ELECTRIC MOTORS

ELECTRIC MOTORS

THEIR INSTALLATION, CONTROL, OPERATION AND MAINTENANCE

BY

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PREFACE.

In this book the author has endeavored to explain the phenomena of electric motors, describe the leading motors and appliances, and give suggestions in a practical manner for their installation, care, and management for the use of practical men. Mathematics have been practically eliminated and illustrations and diagrams relied upon as far as possible to convey the meaning intended.

All of the suggestions contained in the following pages are based on years of personal experience with motors and auxiliary appliances, and upon standard practice adopted by the leading electric companies.

The author is greatly indebted to a large number of electric companies for their kindness in furnishing photographs and diagrams.

N. G. M.

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CHAPTER I.

THEORY OF ELECTRIC MOTORS.

To clearly comprehend the theory and performance of electric motors, a brief review of the principles of direct and alternating-current motors will be helpful. It is necessary to consider carefully the various forces that affect their behavior under different conditions of operation. The action of direct and alternating-current motors is different and will be considered separately.

A motor may be defined as a machine for supplying mechanical power when supplied with electric power from an outside source. The force necessary to maintain motion and perform work is known as torque and is proportional to the current in the armature winding and to the flux in the air-gap.

Assume that there is current through a motor armature winding, that the field is fully excited and that the armature is held from turning. Under these conditions a strong turning or twisting effort will be exerted on the armature but it will be unable to move so that no power will be developed. In such a case all the electromotive force applied is used up in maintaining current through the armature winding against its resistance and the energy is wasted in heating the conductors. If the armature is allowed to turn the motor

is capable of delivering power and the current will enable the motor to carry its load.

The armature current sets up a magnetomotive force in the core which opposes the field magnetomotive force, the resultant of these two forces causing the flux to be shifted, decreasing the density at the leading pole tips and increasing it at the trailing pole tips. This phenomenon is

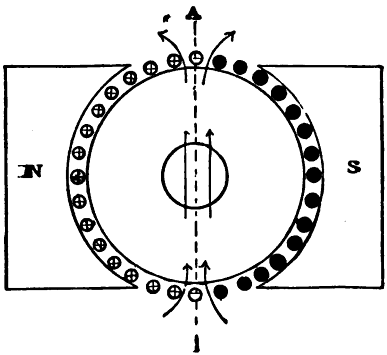

FIG. 1.—Diagram showing direction of current and magnetomotive force in an armature.

known as armature reaction and is proportional to the armature current. As the field flux is shifted backward in a direction opposite to that in which the armature rotates the brushes have to be given a backward lead to obtain a field for sparkless commutation, as will be explained later. This sets up two components in the armature known as cross ampere-turns and back ampere-turns. To more fully illustrate these two com-

ponents refer to Fig. 1, where the light and dark circles about the periphery of the armature represent the conductors, and the dotted line A the theoretical neutral line. The current is assumed to be directed away from the observer in the conductors represented by the dark circles and toward the observer in the light circles, magnetizing the core and setting up a magnetomotive force in the direction of the arrows. This action can be compared to that of a helix as shown in Fig. 2, which illustrates the well known law that "if the current is in the direction of the hands of a clock, when the observer is facing the end, the magnetomotive force will be directed away from him." If the current should be reversed in the armature shown in Fig. 1, the magnetomotive force would assume a direction opposite to that shown.

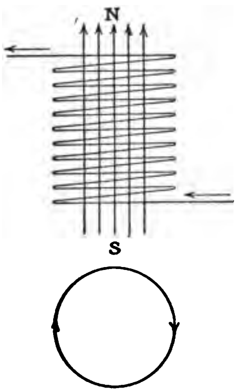

FIG. 2.—Diagram showing direction of current and magnetomotive force in a helix.

The phenomenon explained in connection with Figs. 1 and 2 illustrated the action of the cross ampere-turns whose magnetomotive force acts at right angles to the field magnetomotive force. When a backward lead is given to the brushes, the neutral lines are shifted from A and A' in Fig. 3 to B and B'. Under this condition of operation,

the armature conductors included in the space between the poles form the other component or back ampere-turns which directly oppose the field magnetomotive force. The effect of the two components is to distort or shift the path of the field flux as already explained.

To consider more fully the effects of this armature reaction, refer to Fig. 4 which is a diagram-

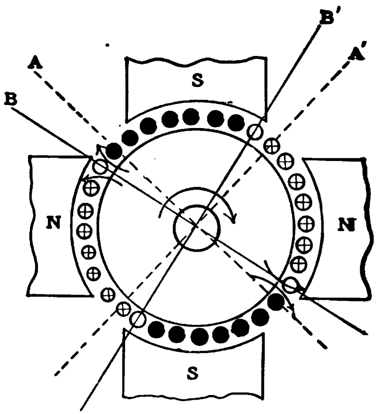

FIG. 3.—Backward lead given to the brushes.

matic representation of the armature winding. It will be seen that the electricity enters the positive brushes (only one of which is shown) divides at *a*, *b* and *c* and leaves at the negative brushes. It is also apparent that as each coil passes under the brushes it is short-circuited as shown at *a*, and when leaving the brush the current through the coil is in the direction opposite to that when

the coil is approaching the brushes. The backward lead of the brushes brings the short-circuited coils under the influence of the field flux so that an electromotive force is generated in them in the same direction that the impressed electromotive force will assume when the coils pass the brushes. If no current were produced in the short circuited coils their inductance would cause an arc from the toe of the brush to the segment passing from under

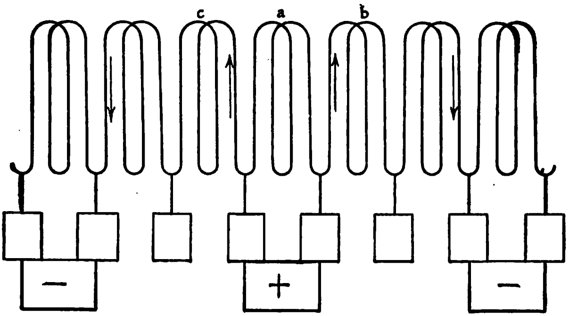

FIG. 4.—Winding diagram.

it, resulting in serious sparking. This condition would be still more exaggerated if the brushes were given a forward lead, as an electromotive force would be generated in the short-circuited coils that would directly oppose the impressed electromotive force as the coil passes from under the brush.

In Fig. 5 the path of the flux of an ordinary multipolar motor is shown by the dotted lines. As in the previous figures, the black circles about the periphery of the armature represent the con-

ductors in which the current is supposed to be directed away from the observer, and the light circles, conductors in which the current is directed toward the observer. The diagram in Fig. 6 shows the effect of moving the brushes backward. Let *n n* represent the theoretical neutral line, then the field magnetomotive force *O F* is laid off at right angles as shown. If the brushes have been shifted through the angle and from the theoretical neutral,

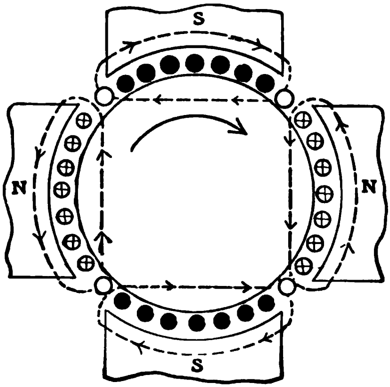

FIG. 5.—Diagram showing path of the armature flux in an ordinary multipolar motor without field current.

the armature magnetomotive force is plotted along *o b* and shown as *o f*. The component of *o f* in line with *n n* is called the cross ampere-turn component and the one at right angles to *n n*, the back ampere-turn component. As is seen from the diagram the cross-ampere turns, *o c*, do not decrease to the field magnetomotive force, but simply tend to dis-

tort the path of the flux. The back-ampere turns, *o d*, however, are exactly opposed to the field magnetomotive force and require an increase of current in the field winding to counter balance their effect.

There is still another factor to be considered in connection with the performance of direct-

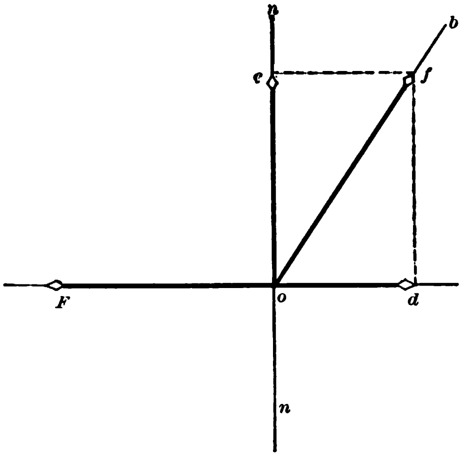

FIG. 6.—Diagram showing theoretical path of the field flux without armature current.

current motors, that is, counter electromotive force. It will be remembered that in the theory of a generator, whenever a conductor is moved in a magnetic field so as to cut lines of force, an electromotive force is generated in the conductor. In a generator this electromotive force is utilized

to establish currents in outside circuits, that is, the electromotive force is the cause of the current and consequently they are both in the same direction.

In a motor there are all the conditions necessary for the generation of an electromotive force in the armature. The armature revolves in a magnetic field and the conductors cut the flux. Of course the armature of a motor is not driven by mechanical power, but is rotated by the reaction that takes place between the field flux and the armature current. This, however, has nothing to do with the generation of an electromotive force. When a motor is in operation, there is an electromotive force generated in its armature which is apposed to the impressed or line electromotive force and consequently opposed to the current through its conductors. This electromotive force is called counter electromotive force. When a motor is running without load the counter electromotive force is nearly equal to the impressed or line electromotive force and there is only enough current to overcome friction and the losses in the motor.

In the most common type of induction motors the rotating part or rotor is generally provided with a winding consisting of a single copper bar in each slot, bolted to short-circuiting rings at the ends. The rotor winding has no electrical connection with any outside circuit. Polyphase e.m.f. is impressed upon the stator windings and the rotating magnetic field set up thereby generates

e.m.f. in the closed circuits formed by the rotor winding. The reaction between the magnetic field and the currents in the rotor causes the latter to rotate. Since the frequency applied to the stator remains constant the number of revolutions per minute of the rotating field is also constant and at no load the rotor revolves at nearly the same speed as the rotating field; the synchronous speed of the rotating magnetic field being determined by the frequency and the number of poles. This is quite different from the direct-current motor in which the speed is determined by the strength of the field and the number of armature series turns.

At full load the speed of the rotor of an induction motor is somewhat less than at no load, this difference in speed, commonly called slip, being due to the fact that at full load larger currents must exist in the rotor, thus requiring a greater generated secondary electromotive force, which in turn depends on the difference between the speed of the rotor and the magnetic field. If the two revolve at exactly the same speed there would be no secondary current and the rotor would exert no torque.

To more fully illustrate the theory of the polyphase induction motor a few examples are of interest. Assume that a horse-shoe magnet be held over a compass. The needle will take a position parallel to the lines of force which are directed from one pole to the other and if the magnet be rotated the needle will endeavor to maintain its

relative position with the lines and rotate also. If a four-pole electro-magnet be substituted for the horse-shoe and a piece of iron suspended by its center and free to revolve for the compass, as shown in Fig. 7, and a current be established in either one of the sets of poles separately the piece of iron will take a position parallel with the lines of force that may exist at that instant. If the two sets of poles are excited at the same time by

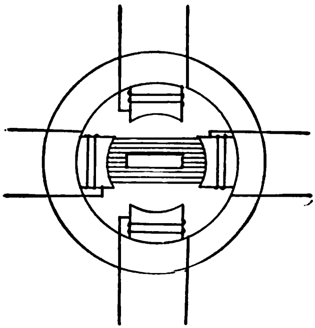

FIG. 7.—Model for study of magnetic field.

currents of equal value, the piece of iron will take a position diagonally half way between the two sets of poles. It can easily be seen that if one of these currents is increasing in value while the other is decreasing the piece of iron will be attracted toward the former until it reaches its maximum value, when if the currents are alternating, the one current having reached its maximum begins to decrease and the other current

having reversed its direction but having begun to increase, attracts the piece of iron away from the first pole and in the same direction of rotation. If this action be continually repeated the piece of iron will revolve, and its direction of rotation will be determined by the phase relation of the two currents. The direction can be reversed by reversing the leads of one phase.

If the piece of iron be replaced by an iron core wound with copper conductors, forming closed coils, secondary currents will be produced in them which will react with the primary flux producing rotation as already explained.

CHAPTER II.

CLASSIFICATION OF MOTORS.

A motor should always be chosen with reference to the character of work it is to perform. For different purposes motors vary as to speed, rating, type of winding, mechanical connection to load, and the method of control. So far as possible a motor whose speed does not vary widely from that of the driven shaft should be used to avoid countershafts and gearing. For intermittent work the limit of a direct-current motor is reached when the sparking at the commutator becomes destructive, and for continuous service the load limit is governed by the rise in temperature of the machine. For these reasons, when the motor is called upon to perform continuous service, it is advisable to choose a larger frame than would be required for intermittent service, that is, when the load fluctuates through wide ranges or where short periods of work and rest alternate.

There are two general divisions of motors as explained in the preceding chapter, the alternating current and the direct current. The direct-current motors will first be considered. In series-wound motors the field coils are connected in series with the armature winding so that the current is the same in both armature and field windings. Fig. 8 shows the connections. The jumper shown in

the illustration is removed when the motor is to be operated reversing and either the armature or the field connections leading to the reversing switch must be reversed. To change the direction of rotation of any type of direct-current motor, either the field or the armature current must alone be reversed.

When a series motor is running light, it takes just enough current to make up for the losses within itself. As the armature increases in speed,

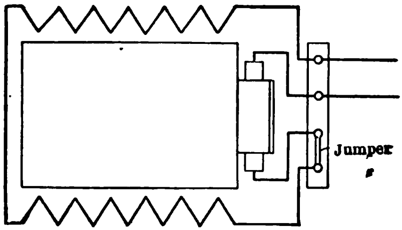

FIG. 8.—Diagram showing connections of field and armature windings in series wound motors.

the counter electromotive force increases and the current rapidly decreases. Since the field winding is in series with the armature winding, the flux is also decreased, and the armature is compelled to still further increase in speed in order to generate its counter electromotive force which at no-load about equals the impressed or line electromotive force. The current necessary to supply the losses in a well designed machine is very small. The no-load current is consequently small and the speed excessively high, in many cases high enough to

injure the motor. For this reason the load should not be thrown entirely off without some means of retarding the speed.

When the motor is loaded, the counter electromotive force decreases slightly, allowing the current to increase, thus increasing the field flux and producing a correspondingly stronger torque. As the field flux increases with the load, the speed decreases, giving a different speed for each load. The speed is varied by introducing resistance in circuit with the motor.

The field magnets are sometimes wound with enough turns so that the magnetic circuit becomes fully saturated at a small percentage of the full-load current, producing a field that remains fairly constant over a considerable range of load and thus reduces the variations of speed with the variations of load.

The characteristics of a series-wound motor may be summarized as follows: Its speed will vary through a wide range with changes of loads; it will keep the power from changing greatly; it is notably sparkless; it has a very strong starting torque and it will race if allowed to run free. The series-wound motor is especially valuable for electric cranes and hoists, turn tables etc., where frequent reversals are necessary, and where the speed of the motor is constantly under the control of the operator. It is also satisfactory for driving a definitely known load properly proportioned to the size of the motor, and directly connected to

it, such as for example, a fan under free circulation. A typical series-wound motor equipped with an electric brake is shown in Fig. 9.

For steady continuous service the shunt-wound motor is used more than any other type of direct-current machine because of its valuable speed-

FIG. 9.—Series-wound motor with solenoid brake.

regulating qualities which adapt it to the operation of machinery of all kinds that runs at constant speed. In a shunt-wound motor the field winding consists of many turns of fine wire and is connected directly across the mains when the motor is running. The connections are shown in Fig. 10.

One side of the shunt winding is connected directly to one side of the armature circuit at the motor and the other side to the line through the main switch. When the main switch is closed the field is excited and then by cutting out the resistance of the starting rheostat gradually the current in the armature increases. Owing to the high resistance of the field winding and the low resistance of the armature winding of a shunt-wound motor, if the field circuit were not closed

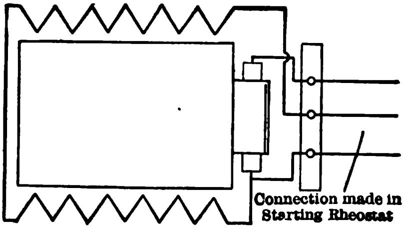

FIG. 10.—Diagram showing connections of windings in shunt-wound motors.

before that of the armature, it would practically be short-circuited by the armature winding and would receive little or no current, causing the motor to race badly and spark at the commutator. The field coils will supply the same magnetomotive force when there is no demagnetizing action of the armature. When the motor is running free, the only load which the armature current has to supply is the friction and other losses in the armature. The amount of energy which the motor will take from the line will be just sufficient to counter-

balance these losses. When a load is applied to the motor it requires sufficient current to enable the armature to produce torque enough to carry the load. In order to allow this current to be established the counter electromotive force must decrease slightly and as the flux is nearly constant the speed lowers slightly. The armature reaction, however, weakens the field flux and slightly increases the speed so that the variation from no load to full load is very small. When the load is thrown off there is no tendency to race and the motor automatically adjusts itself to changes in load.

The speed of a shunt-wound motor may be regulated within certain limits depending upon the design. The method of regulation in common use is to introduce resistance in the field circuit and increase the speed. By decreasing the amount of resistance in the field circuit, the speed of the motor is correspondingly reduced. The shunt-wound motor should be used where uniform speed is required under changing load, and is commonly chosen for driving line shafting, or where more than one machine is to be driven from one motor. Its operation may be compared to that of a well governed steam engine.

A compound-wound motor has both a series and shunt winding, as shown in Fig. 11, and combines, to a large extent, the advantages of both types of motors. Its operation corresponds more nearly to one or the other depending upon the rela-

tive proportions of the two windings. The compound-wound motor will vary in speed with changes of load more than the shunt-wound motor, but will not race at no load or slow down under heavy load as much as a series-wound motor. It is well adapted to the individual driving of such machines as printing presses, machine tools having a reciprocating motion such as planers, shapers, slotters, etc., self-starting pumps, fans of all kinds,

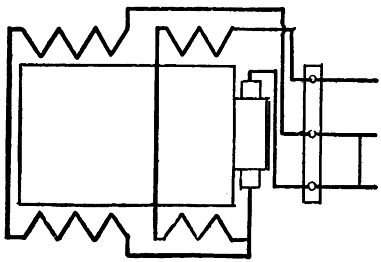

FIG. 11.—Diagram showing connections of compound-wound motors.

and machinery requiring a fairly steady speed and heavy starting torque, particularly where the machine is frequently started and stopped or reversed. An open type of compound-wound motor is shown in Fig. 12. In this figure the series coil is indicated at 1 and the shunt coil at 2. It will be noticed that an air space is provided between the two coils. This is for the purpose of ventilation. Fig. 13 shows a semi-enclosed type of motor. An entirely enclosed type differs from this only in

that the covers 1 are solid. Either of these types may be shunt or compound wound. A view through the frame of a shunt-wound bipolar motor is illustrated in Fig. 14.

There are several modifications of the com-

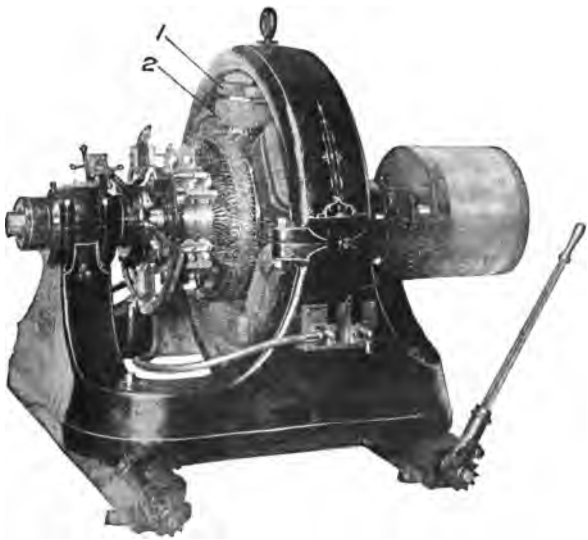

FIG. 12.—Open-type compound-wound motor.

pound-wound motor the most common being the mill type motor, shown in Fig. 15, and the elevator motor. The former is especially adapted to screwdowns, heavy ladle cranes, and mill tables including main tables for blooming mills, where the service is extremely severe, and traveling and

intermediate tables for rolling mills of all classes. This kind of service requires a motor capable of handling excessive overloads with reliability. They are of the enclosed type and especially adapted to heavy and intermittent service. The

FIG. 13.—Semi-enclosed motor.

series winding predominates, but this type of motor is usually provided with a shunt winding to prevent racing when the load is removed.

The elevator type of motor is provided with a series and two shunt windings. The series winding is used when starting and is cut out by the

controller when the motor is up to speed. It then runs with one shunt winding. The second shunt winding is thrown into circuit when stopping at the various floors.

A type of direct-current motor that is in quite general use is shown in Fig. 16. It is provided with an extra set of poles attached to the frame between the main poles. The winding of these

FIG. 14.—Frame of a shunt-wound bipolar motor.

poles is connected in series with the armature, their function being to maintain a field for sparkless commutation irrespective of the distortion of the main field flux caused by armature reaction when the field flux is decreased for speed regulation. This type of motor is designated by different names as inter-pole motor, commutating-pole motor, auxiliary-pole motor, etc. These motors are

built to give a high range of speeds on a single voltage circuit by means of weakening the field flux.

Fig. 17 illustrates graphically the action of an interpole motor. For the sake of simplicity, a bipolar model is shown. In the figure N and S represent the main poles, and N' and S' the auxiliary or interpoles. The brushes on an interpole motor are set exactly on the theoretical neutral line; therefore, there are no back ampere-

FIG. 15.—Mill type motor.

turns. In the figure, the vector, $O\,F$, represents the m.m.f. of the main field poles, both in direction and value. This force is constant for any given field excitation. $O\,f$ represents the m.m.f. due to the current in the armature, and is directly proportional to the load, and were it not opposed and completely neutralized by the m.m.f., $O\,f'$, due to the current in the auxiliary field coils, the main field flux would be distorted and armature reaction result. However, the auxiliary winding

being in series with the armature winding, the m.m.fs., *O f* and *O f′* will neutralize each other at all loads.

The interpole type of motor is designed especially for the operation of machine tools such as lathes, boring mills, milling machines, drills and machines

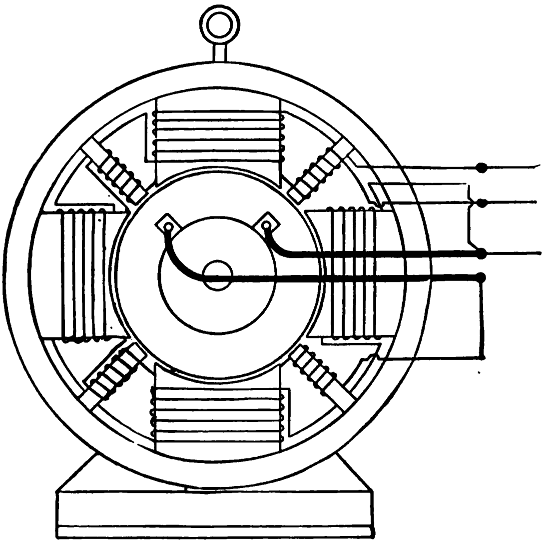

FIG. 16.—Diagram of connections of an interpole direct-current motor.

of a similar character. Fig. 18 illustrates this type of motor.

A modification of the interpole motor is found in the "Thompson-Ryan" motor in which the difficulties of shunt regulation are all removed by means of a special winding called "balancing

coils." This device consists of a stationary winding surrounding the armature of the motor and connected in series with it. This winding has a double effect: Firstly, it neutralizes armature reaction and thoroughly prevents distortion of the magnetic field due to such reaction. Secondly, it builds up and maintains a commutation field of just the right strength for perfect commuta-

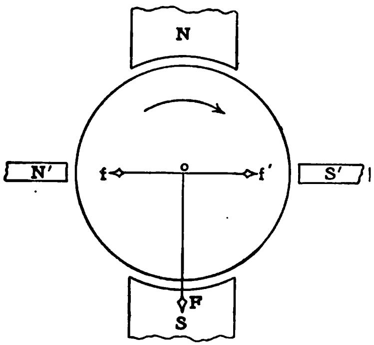

FIG. 17.—Graphical illustration of the action of an interpole motor.

tion. This commutation field being produced entirely by the balancing coils, is independent of the shunt fields, and, therefore, the latter may be weakened or strengthened at will without interfering with the commutation of the motor.

Armature reaction, being neutralized, does not interfere with nor distort the shunt field however weak the latter may be. It is, therefore, possible

by the use of these coils, to increase the speed of the shunt motor not only 50 per cent. but even twenty times this amount, giving a speed range of 5 to 1 or even 10 to 1 by weakening the shunt field, and still have the operation of the motor

FIG. 18.—Interpole motor.

entirely satisfactory, even under full load or overload. A motor of this class, when adjusted for any particular speed, will maintain that speed approximately for all loads, which is a condition very necessary for driving machine tools. Since the torque diminishes as the speed increases, the

horsepower capacity of such a motor, being the product of the torque by the speed, is constant for all speeds; this also is a condition well suited for driving tools.

The field ring in the larger sizes is built of two steel castings which carry the pole pieces for the

FIG. 19.—Field ring of a "Thompson-Ryan motor."

shunt field coils. Inside these pole pieces is a laminated bushing ring upon which the "balancing coils" are wound. These balancing coils, on all motors except those of larger sizes, are form wound and easily removable from the bushing ring which carries them. In the larger sizes these

coils are hand wound similar to standard dynamo construction.

In the smaller sized motors the field ring and balancing coil bushing are combined in a single laminated ring which carries both the balancing and field coils, as shown in Fig. 19. This laminated

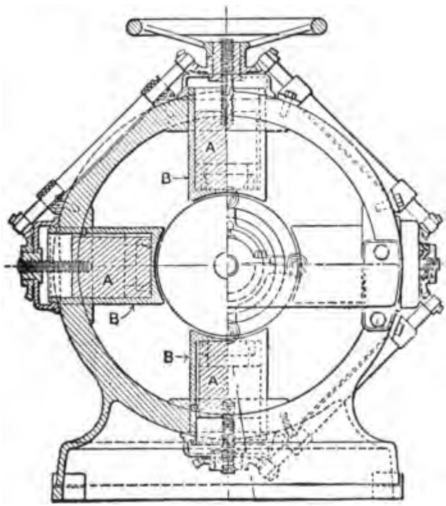

FIG. 20.—4-pole motor with plunger mechanism.

field ring is enclosed in a cast iron case which also carries the bearing frames and the feet for the motor.

There are mechanical devices also for varying the speed of direct-current motors, one being shown in Fig. 20. The novel feature of this type of

machine lies in the special construction of the pole pieces which are hollow and are provided with iron cores or plungers that are adjustable. When the plunger is withdrawn, the air column within the pole pieces offers a gradually increasing barrier to the effects of armature reaction until, when the field strength is reduced to a minimum by fully withdrawing the plungers, the effects of reaction are reduced to a minimum from lack of a conducting path through which to act. Further, the construction of the pole pieces and plunger is such that, as the volume of magnetism is reduced by the movement on the plunger, the remaining magnetic flux is forced more and more in the direction of the pole tips, saturating them and thus insuring a magnetic field of sufficient strength to maintain sparkless commutation. The tips being saturated the flux density in the commutating fringe remains constant and prevents a shifting of the flux.

These motors give a constant power output and carry their full rated load at any speed within their range. The sectional view conveys a clear idea of the internal construction of the multipolar motors. Like the ordinary shunt-wound motor with field regulating rheostat, these motors depend upon the variation of field strength for speed variation. The pole pieces consist of shells over which the magnetizing coil is wound, within which is a solid core. By means of a hand-wheel this inner core or plunger is adjusted in a direction radial to the center of the armature and is so arranged that a slight

variation of its position within the magnetized shell produces a considerable difference in the reluctance of the magnetic circuit of which the plunger forms a part. When the plunger is adjusted so that its inner end comes nearest to the armature, the magnetic circuit has the least reluctance. At this point the minimum speed is obtained. In these motors no resistance is used in

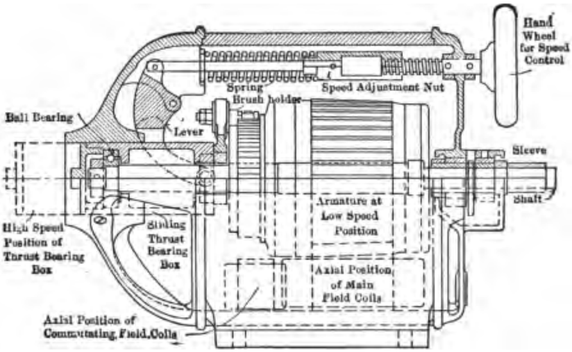

FIG. 21.—Adjustable speed motor.

the field circuit for speed regulation and when once adjusted the motor operates at constant speed regardless of load.

Another method of varying the speed of a motor is shown in Fig. 21. The motor is equipped with a mechanical device whereby the armature with the brushes is made to move axially away from the main field poles and into the influence of the commutating poles. As the armature is with-

drawn the magnetic reluctance increases and the magnetic flux decreases, the result being increased speed. The armature is slightly larger at one end than the other. This conical shape is used in order more quickly to increase the air-gap, which it does as the armature is withdrawn from the pole pieces. With the decrease in magnetic area a greater variation in flux is obtained producing a great variation in speed. Fig. 21 shows the hand wheel, adjustment nut and split lever, by which the armature with the thrust bearing box, rocker arm, and brushes, is moved axially away from the main field poles and into the influence of the commutating field. The tendency to spark at the brushes when the armature is withdrawn from the main fields is counteracted by the influence of the commutating poles resulting in sparkless commutation.

The thrust bearing box as shown, supports the commutator end of the armature, sliding in the yoke, while the annular ball bearing, completely closed and protected from dirt, is used to carry both the thrust and radial load at this end of the shaft. The thrust bearing, carrying the armature with it, is moved out by turning the hand wheel. The hand wheel is attached to a threaded shaft which passes into the motor frame and engages the adjustment nut, which in turn works the lever as shown in the illustration. At the pinion end of the motor there is a sleeve through which the armature shaft slides to various positions of ad-

justment, the sleeve itself being in a fixed position and revolving with the shaft in the bushing in the yoke. The full variation of the speed is obtained with a few revolutions of the hand wheel, depending on the speed range and size of the motor. The spring is provided to counterbalance the magnetic pull of the armature, making the shifting simple and easy.

So far only direct-current motors have been described, but in a great many cases alternating-current motors are used. They must be of such design that they will not only be self-starting but will give a strong starting torque. This is necessary in all cases where the motor has to start under load. Such motors must also be designed so that they can frequently be started and stopped and in general fulfill the same requirements as direct-current machines. These requirements are fulfilled by induction motors, which are in general use. They are generally made for operation on two or three-phase circuits, although they are also made to operate on single-phase circuits.

The stator is built up out of disks with teeth on the inner circumference which form slots when the core is assembled. The coils are placed in the slots and the winding when completed resembles the distributed winding of a direct current armature.

One type of single-phase motor is provided with a winding similar to that of a three-phase induction motor. The motor is rendered self starting

by means of a starting box containing resistance and reactance, and a double-throw switch. The switch is first thrown to the starting position, and when the motor has attained almost full speed it is quickly thrown into the running position, the object being to first connect the resistance and reactance in circuit with the motor, and then disconnect it. The accompanying illustration shows the diagram of connections. Sometimes a condenser is used instead of the resistance, as shown by the dotted lines.

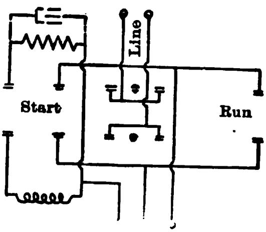

FIG. 22.–Diagram showing connections for starting single-phase motor (three-phase winding).

There are a number of designs embodying modifications peculiar to themselves. In some makes of single-phase motors there are two windings, a main winding and an auxiliary winding where only one resistance is used. The main winding generally occupies two thirds of the slots, the remaining third being used for the auxiliary or starting winding. The motor thus starts as an imperfect two-phase motor. The starting phase generally receives either half the number of convolutions as the main phase or twice as many. Figs. 23 and 24 show the connections of such a motor. In Fig. 23 the resistance A is in series with the main phase at starting, the auxiliary phase being directly between the terminals. In Fig. 24

the resistance is parallel with the auxiliary phase which is in series with the main phase. During the throwing over of the switch from the starting to the running position the motor is temporarily disconnected from the line. Another modification of the single-phase motor is the repulsion

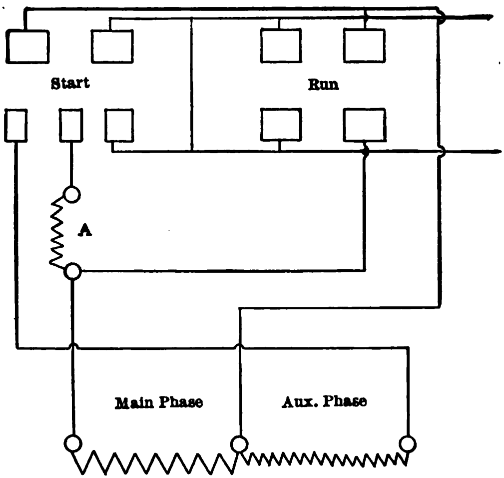

Fig. 23.—Diagram showing connections for starting singl-e phase motors (two-phase winding).

motor, which employs an armature similar to that of a direct-current motor. The connections vary in different makes. Some of the motors are so arranged that they start as repulsion motors and operate as ordinary induction motors. The brushes are connected together when the machine is at rest, at a predetermined speed they are

automatically raised from the commutator and the winding short-circuited. It is then similar in principle to a squirrel-cage rotor. Such a motor is illustrated in Fig. 25 and sectionally in Fig. 26. The automatic device is a centrifugal governor contained in the armature. At the

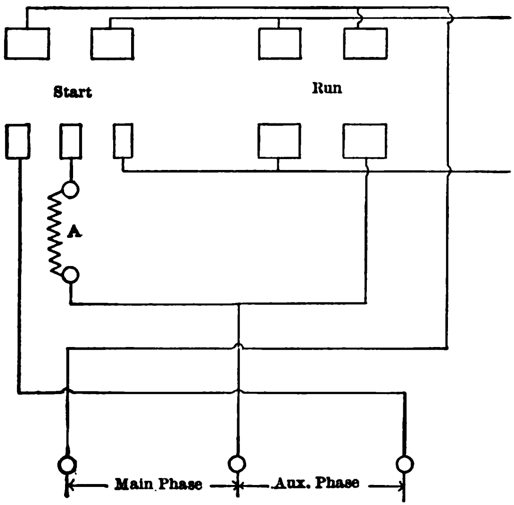

FIG. 24.—Diagram showing connections for starting single-phase motors (two-phase winding).

proper speed it comes into action, throwing into the commutator a short-circuiting link, which transforms the motor from the repulsion to the induction type. This automatic governor is shown in the sectional view.

The ordinary single-phase motor gives but a

small starting torque, generally about 25 or 30 per cent. of the full load running torque. The repulsion type gives a high starting torque.

The polyphase squirrel-cage induction motors are more generally used and owing to their extreme simplicity and the indestructible nature of the rotor winding are better adapted to many kinds of service.

FIG. 25.—Single-phase motor.

The winding of a two-phase motor is illustrated diagrammatically in Fig. 27. A three-phase delta-connected winding is shown in Fig. 28. The open Y or star winding is also used for three-phase motors and differs only in that each phase of the motor winding is connected to one phase of the line and the three free ends are joined together as shown in Fig. 29.

The constant speed induction motor is adapted to constant speed work of all classes and its inherent characteristics resemble those of a direct-

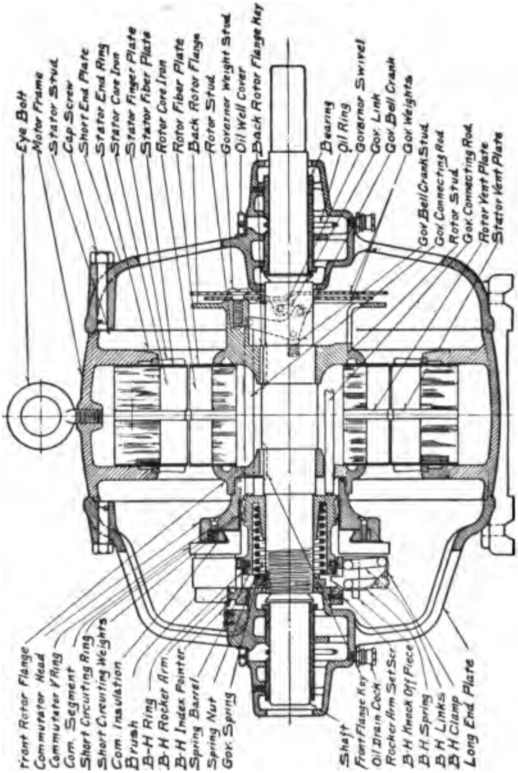

FIG. 26.—Cross-section of single-phase motor.

current shunt-wound motor. The stator of a motor of this type is shown in Fig. 30 and a squirrel-cager otor is illustrated in Fig. 31.

A modification of the above mentioned motor is used for many purposes. The stator of this motor is constructed like the constant speed machine but the secondary or rotor is provided with a polar winding similar to that of the revolving armature of a three-phase alternator. An internal or external resistance is connected in circuit with the rotor windings which may be cut out or in at will, to

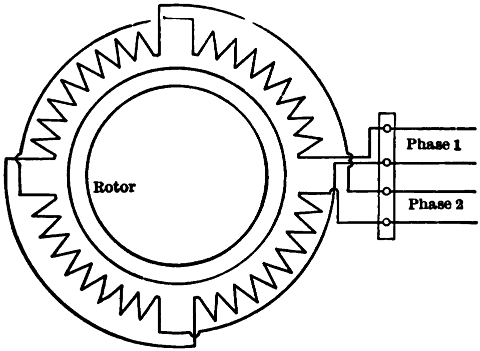

FIG. 27.—Winding diagram of a two-phase motor.

vary the speed or may be used for starting only. This arrangement is to vary the speed or to reduce the current and increase the torque at starting. This type of motor is especially valuable for use where voltage regulation is important as is the case where there are lighting circuits on the same feeder.

A type of motor with an internal resistance is shown in Fig. 32.

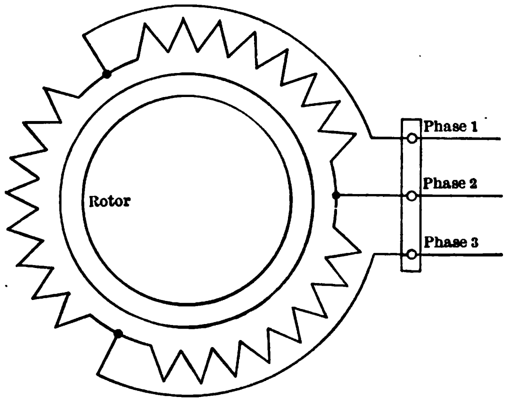

FIG. 28.—Diagram of a three-phase delta-connected winding.

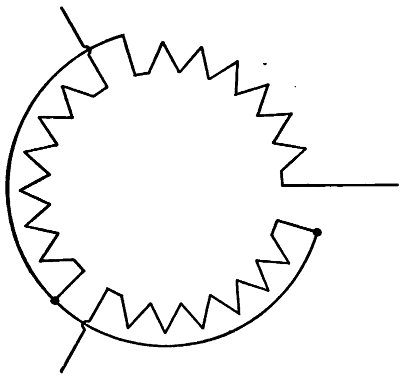

FIG. 29.—Diagram of a three-phase open Y or star winding.

The resistance in motors of about 50 h.p. and under consists of iron grids enclosed in a triangular cover which is bolted to the end plates holding

FIG. 30.—Stator of a constant-speed induction motor.

FIG. 31.—Squirrel-cage rotor.

the rotor laminations together. It is short-circuited by sliding laminated spring-metal brushes along the inner surface of the grids. The brushes

are supported by a metal sleeve on the shaft, which is operated by a lever secured to the bearing bracket and located just above it.

A rod passing through the end of the shaft operates the short-circuiting arrangement in motors of about 25 h.p. and under. For motors

FIG. 32.—Induction motor with internal resistance.

over 50 h.p. cylindrical resistances of German silver wound on edge are used. These coils are bolted 120 degrees apart to bosses on the spider hub and are clamped together by a ring on their front end. The operation of the brush yoke is similar to that used for the cast grid resistance.

In motors of this type with external resistance and controller the three leads of the rotor winding are connected to three slip rings upon which three brushes rest. The connections are shown in Fig. 33. The primary of either the motor with external or internal resistance may be provided with two or three-phase windings adapting the motor to two or three-phase circuits. This type

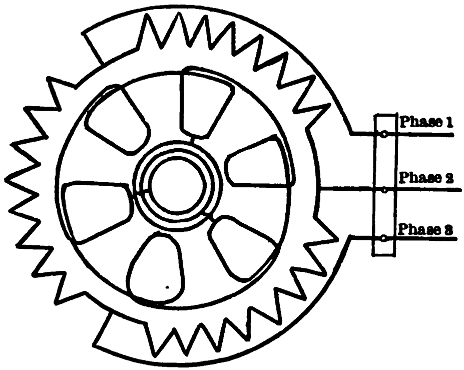

FIG. 33.—Diagram showing connections between rotor winding and slip rings.

of motor having external resistance is illustrated in Fig. 34. The variable speed induction motors are adapted to the operation of hoists, elevators and machinery where variable speed within moderate limits is required.

The synchronous motor, shown diagrammatically in Fig. 35, is very similar in construction to the revolving armature alternator. It is constructed

for operation on single, two and three-phase circuits. This type of motor is called synchronous because it operates in synchronism with the generator. The field of such a motor must be

FIG. 34.—Induction motor with external resistance.

excited from a separate direct-current machine in the same manner as an alternator.

Single-phase synchronous motors are not self starting and must first be brought up to speed by some outside source such as a separate motor, when they will operate by their own effort. Syn-

chronous motors operate as though they were geared to the alternator and will give two or three times normal torque. Two or three-phase machines will start from rest as induction motors and run up to synchronism. They are started as induction motors with the direct-current field

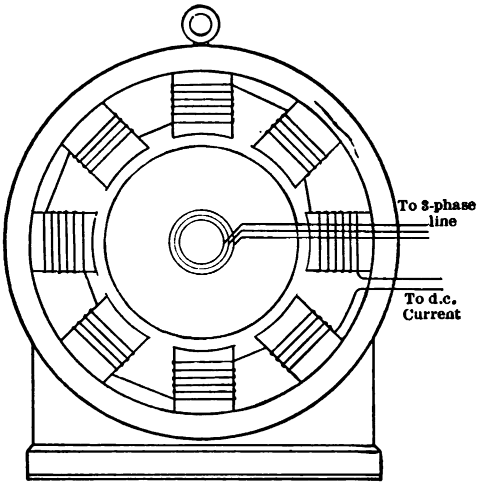

FIG. 35.—Diagram of synchronous motor.

circuit left open. Their starting torque is small, only about twenty-five per cent. of the running torque and the load should not be thrown on until synchronism is reached. It is necessary to provide some source from which direct current may be obtained for exciting the fields which may be accomplished by belting a small direct-current

generator to the shaft, the exciting current not being used until the motor reaches synchronism.

The field circuit of a polyphase synchronous motor must be opened in several places when starting or an e.m.f. of high enough value to endanger the insulation will be generated in it.

The synchronous motor is largely used for transmission purposes, and also finds frequent uses in industrial work, in connection with motor-generator sets used as interconnecting sets between alternating and direct-current systems.

CHAPTER III.

CONTROL AND AUXILIARY APPARATUS.

The salient features of the various types of motors have been considered and the particular classes of work they are adapted to enumerated. The manner of controlling them is the next feature to be reviewed. The control apparatus is fully as important as the motors themselves and should be selected for attaining the most economical and satisfactory results.

Before giving detailed descriptions of the various types of controlling apparatus a general review of the principles of control will be of interest.

Direct-current motors, as explained in a previous chapter, develop a counter electromotive force that opposes the impressed electromotive force so that the current is only proportional to the load. When a motor is at rest, however, no counter electromotive force is developed and the windings virtually short circuit the line and a heavy rush of current would follow the closing of the motor switch if no resistance were interposed. This resistance is in the form of the familiar starting box or may be a separate unit and adjusted by means of a controller. At each step of the controller or starting box a portion of the resistance is cut out, the motor in the mean time is accelera-

ting and develops a counter electromotive force proportional to the speed. When the resistance is all cut out the motor has attained normal speed.

The resistances are made in several different forms such as wire wound in spiral coils, metal ribbon or cast grids. The materials used are generally iron or steel, german silver, or a special alloy.

For varying the speed of a shunt or compound-wound motor resistance is cut in or out of circuit with the shunt field winding. This may be accomplished by means of an ordinary rheostat or by the use of a controller which both starts and stops the motor, and regulates the amount of resistance in the field circuit. This latter method is to be preferred as it eliminates the danger of starting a motor with weakened field which generally causes flashing at the commutator of the motor and excessive speed.

There are several types of automatic control systems which are operated from a small master controller that may be located where convenience dictates. These systems vary from the ordinary hand control only in that the various sections of resistance are cut out or in automatically by specially constructed switches. The principle of operation of the manually operated or automatic controllers are identical.

Series motors are generally operated reversing and the general arrangement is to combine a reversing switch with the controller so that when

the handle is moved in one direction the motor accelerates and when the handle is moved in a reverse direction the motor slows down by reason of the resistance being thrown into circuit and as the handle is moved beyond the normal off position the current in either the feed or armature winding of the motor is reversed, changing the direction of rotation.

Alternating-current motors are started, stopped and regulated in a somewhat different manner. The single-phase motor is started by several different methods which are explained in detail in the following pages.

For starting a polyphase constant speed induction motor the starter consists of an auto-transformer in connection with a suitable switch. The coils of the auto-transformer have intermediate tops so that as the switch handle is turned successively increasing voltages are supplied to the stator windings.

The variable speed type of induction motor employs a resistance connected to the windings of the rotor and it is started, stopped or controlled by varying the resistance which is done by means of a suitable switch or controller.

Synchronous motors may be started by connecting directly to the line, but it is customary to use an auto-transformer in a similar manner to that employed with an induction motor.

Automatic systems of control can be used in connection with alternating-current motors as

well as direct-current and are similar in principle, with the exception that with direct current systems the sections of resistance are cut out or in, where with alternating current systems the motor is connected to various taps of the autotransformer.

The various types of regulation and the different apparatus used in connection with them will now be taken up in detail.

The connections of rheostats for series, shunt

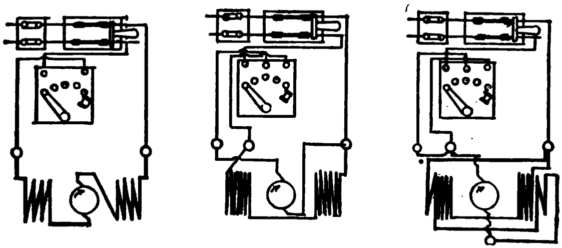

FIG. 36.—Connection diagrams of two-pole series, shunt and compound motors.

and compound-wound motors are shown in Fig. 36. These rheostats are all built upon the same general design but vary in details. A Ward-Leonard Type *S K E* motor starter is shown in Fig. 37. The overload release consists of an independent interlocking circuit breaker which gives absolute protection to the motor and rheostat, and the no-voltage release responds to the line voltage only. To prevent arcing at the initial contact of the starter an independent, spring-actuated, circuit-

closing switch is supplied, which always opens the circuit with a quick break. In sizes above 10 h.p. a magnetic blow-out is supplied.

A good arrangement for the motor auxiliaries is to mount them on a panel as shown in Fig. 38.

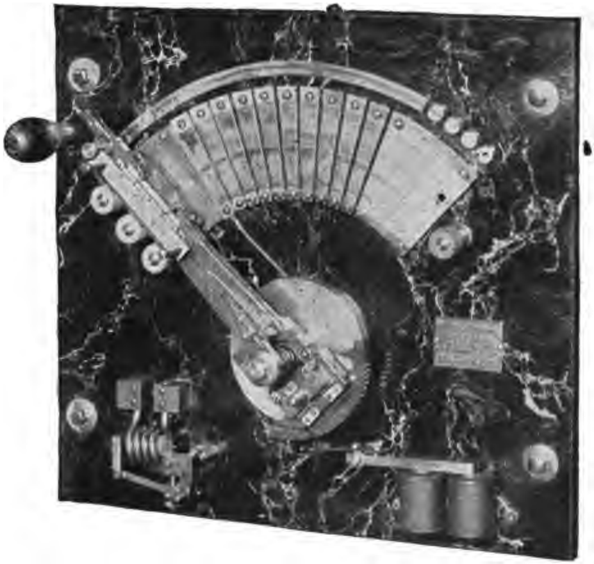

FIG. 37A.—Motor starter.

A similar panel provided with both fuses and circuit breakers, conforming to U. S. Navy specifications is illustrated in Fig. 39. The panels are operated as follows: The overload circuit breaker is first closed, then the starting lever is moved for-

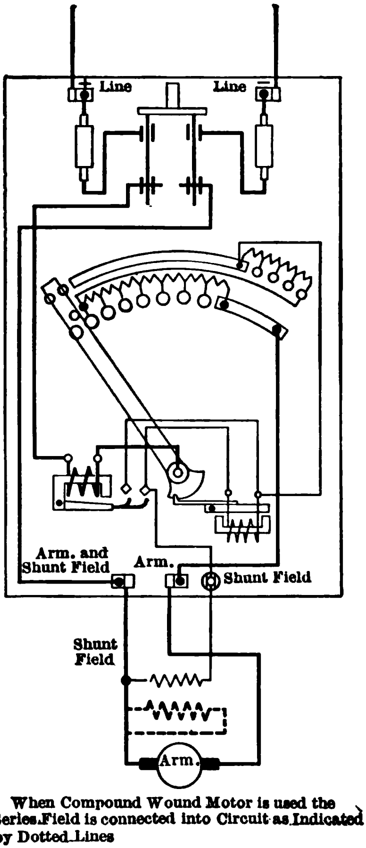

FIG. 37B.—Connection diagram of the motor starter shown in Fig. 37A.

ward, closing the initial auxiliary contact switch, whereby the circuit to the motor armature winding is completed through the overload circuit

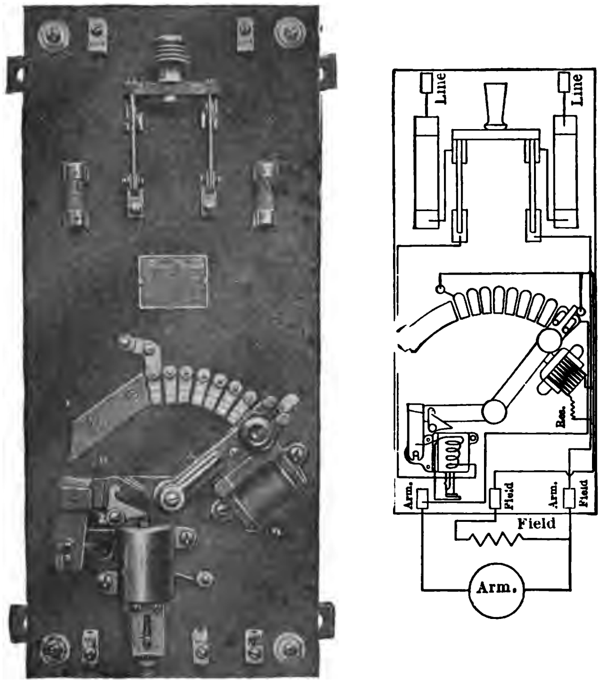

FIG. 38.—Motor starting panel and connection diagram.

breaker and starting resistance, and the shunt field winding is connected directly across the line. The motor will then start promptly with the lever at the initial contact and the continued movement

of the rheostat lever will cut out the armature resistance and bring the motor up to full speed.

A motor starter with switch and fuses attached is shown in Fig. 40. This combination can be used to start any type of direct-current motor

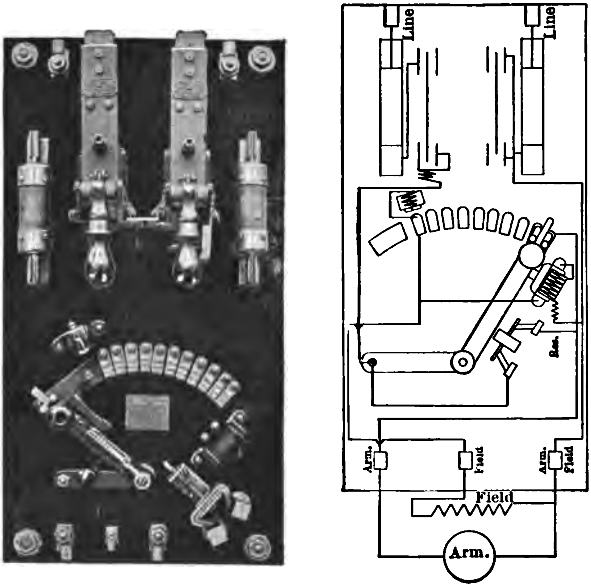

Fig. 39.—Motor starting panel provided with fuses and circuit breaker. Diagram of connections.

of the proper rated horsepower and voltage, whether series, shunt or compound-wound, regardless of speed rating and allows speed control by field regulation. The connections of a reversing starter are shown in Fig. 41.

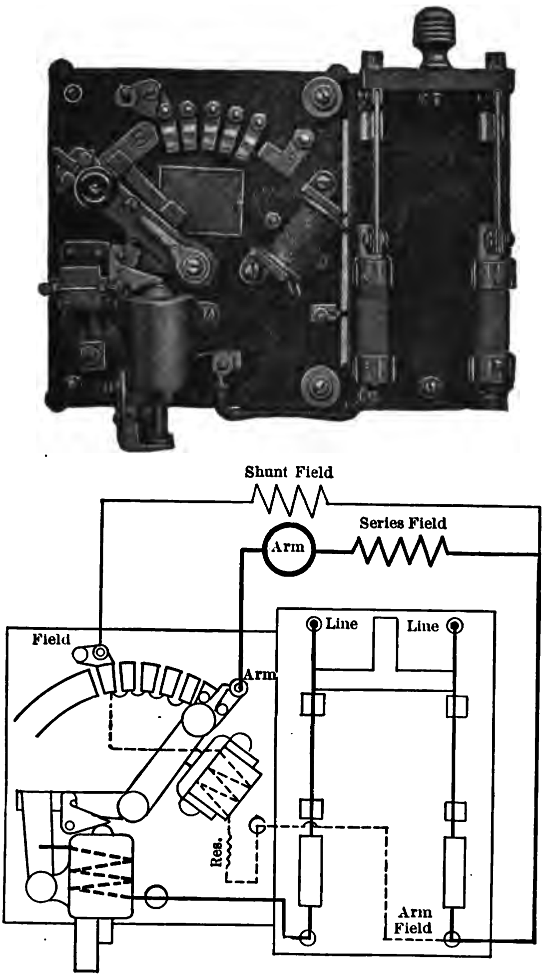

FIG. 40.—Motor starting panel with switch and fuses attached.

The connection diagrams in Fig. 40 and 41 are for compound-wound motors. For shunt-wound motors the series field is omitted. For series-wound motors the shunt field and its connection to the starter are omitted.

For use in locations that are very damp or where

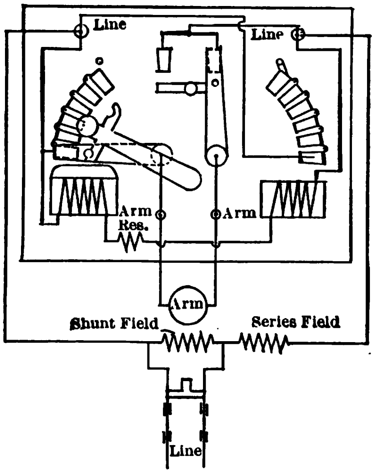

FIG. 41.—Reversing motor starter with automatic "no-voltage" release.

the apparatus is subjected to dust or inflammable gases, an enclosed rheostat is desirable.

There are several types of resistances used in the various makes of starters. An enclosed resistance used by the Ward Leonard Electric Company is illustrated in Fig. 42. The resistance

material is composed of a special alloy and is in the form of a metal ribbon, the width depending upon the current. The ribbon is reflexed upon itself so as to obtain a large amount of surface in a small space. The ribbon is attached to the slate by means of suitable pins, with several layers of sheet asbestos intervening so that comparatively little heat can be transmitted to the slate. A

FIG. 42.—Enclosed resistance.

hollow casting is fastened to the slate, enclosing the resistance. This casting is filled with sand through an opening which is afterward closed by means of a renewable plug.

Fig. 43 shows the interior of a Westinghouse rheostat with bar-wound resistance. A unit consists of an iron bar wrapped with asbestos over which the resistance wire is wound.

In rheostats of large size, cast metal resistance grids are generally used. Several such grids are illustrated in Fig. 44.

A type of controller for crane, hoist and similar applications, made by The Electric Controller and Supply Company is illustrated in Fig. 45.

These controllers are self contained, compact and all parts are interchangeable. The resistance units are supported by the face of the controller

FIG. 43.—Interior of a rheostat with bar-wound resistance.

which also carries the contact segments, operating arm and terminals. The standard U controllers are furnished with an ebonized handle with a simple forward and backward movement. Reversal and acceleration are both accomplished by this means, there being no reverse switch. The type shown in Fig. 45 is intended especially for iron and steel mill service. Wiring diagrams for this controller when used with a series motor and a magnetic safety brake are shown in Fig. 46.

The details of a Westinghouse magnetic brake are given in Fig. 47. The action of this type of brake is controlled by an electromagnet which consists of a magnet case, coil, and armature plate, and is mounted on the studs which hold the stationary friction plates. The magnet case contains the coil, the spring and the spring cup. Three spuds riveted to the armature pole, extend into the friction case and transmit the pressure of the spring to the

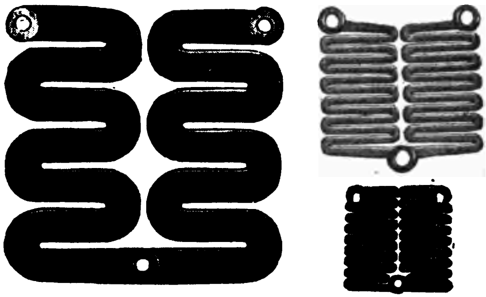

FIG. 44.—Resistance units of grid form.

friction plates. The magnet coil is form-wound and thoroughly insulated. It is generally proportioned for series connection but may be shunt-wound when required. The spring cover is provided with an adjusting screw by means of which the tension may be altered and the braking power varied within certain limits. When the operating controller is in the off position the magnet of the brake is dead and the pressure of the spring is transmitted through the armature plate and spuds

to the friction plates, so that the friction disks and the stationary plates are clamped together and the shaft is held. The application of e.m.f. to the motor energizes the brake magnet, for the magnet coil is connected in the motor circuit,

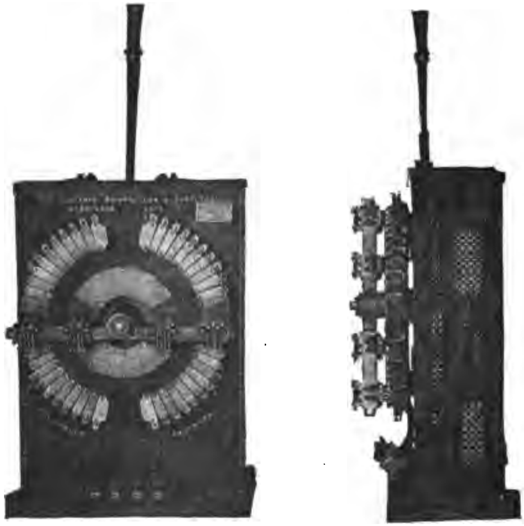

FIG. 45.—Dinkey ventilated controller. Cast grid resistance.

which attracts the face of the magnet case, compressing the spring and releasing the friction plates and disks. The shaft can then turn free and the hub drives the friction disks inside the friction case.

A complete wiring diagram for a three-motor

overhead traveling crane, showing controllers with separate reversing switches is shown in Fig. 48.

In controlling variable speed motors by weakening the field it is advisable to control both the starting and regulating resistance by one handle so that the motor cannot be started with weakened field. A motor starter embodying these features

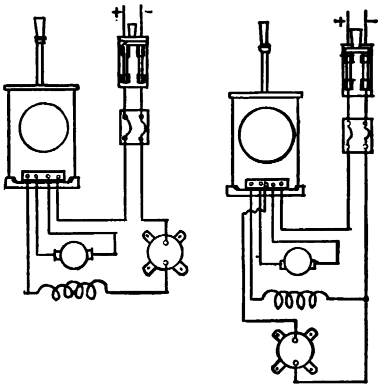

FIG. 46.—Wiring diagram of Dinkey ventilated controller. Magnetic brake connected in series and in shunt.

is shown in Fig. 49. When a separate field rheostat is employed it should be provided with a no-voltage release protective device. When controllers are used a circuit breaker with a no-voltage release should be connected in circuit to prevent the motor from receiving full current when the supply fails momentarily and again comes on.

A starter for large motors is illustrated in Fig.

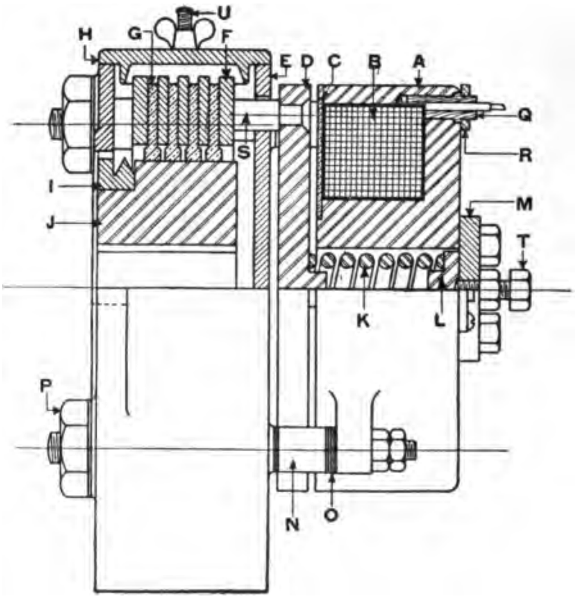

Fig. 47.—Detail of magnetic brake for use with series-wound d.c. motors. A, magnet case, special steel; B, coil, form wound and impregnated; C, retaining plate, brass; D, armature plate, steel; E, friction case, cast iron; F, friction plate, stationary, cast iron; G, friction plate, rotating, brass; H, cover, cast iron; I, oil slinger, cast iron; J, hub steel (keys cut on hub); K, spring, steel; L, spring cap, cast iron; M, spring cover, cast iron; N, plate stud; O, distance washer; P, plate stud nut; Q, terminal bushing; R, terminal guard; S, armature spud; T, adjusting screw; U, cover clamp.

50. This type of motor-starting rheostat differs from the ordinary style used for small motors in that the sliding contacts are entirely done away with and a system of switches substituted.

In building starting boxes with sliding contact it is necessary to divide the resistance into a large number of steps, in order to reduce to a minimum

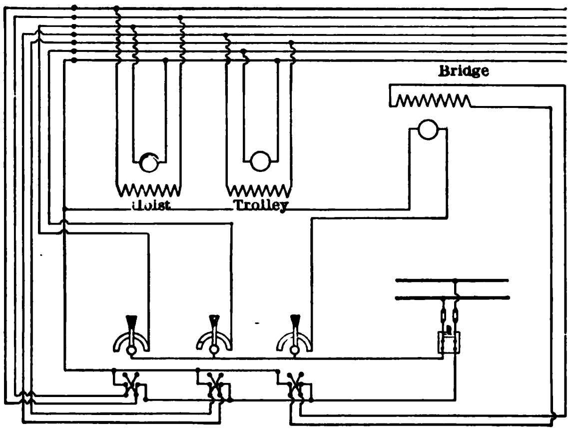

FIG. 48.—Wiring diagram for a three-motor overhead traveling crane.

the sparking which occurs when the contact is moved from one segment to another. There is always some sparking with this type of construction. With the multiple switch system there is no sparking whatever at the switch in starting a motor, whether under load or not, and it is not necessary to divide the resistance into as

many sections. The peculiar construction of these switches insures good contact the instant any contact at all is made. The switches differ from the ordinary knife switch in that they do not have to be pushed into clips before the full carrying ca-

FIG. 49A.—Motor starter controlling both starting and regulating resistance by one hand.

pacity is obtained. The contact is made by a large number of thin leaves of copper which press against a hard copper surface.

The first switch on the left-hand side is held closed by an electromagnet and all the others by

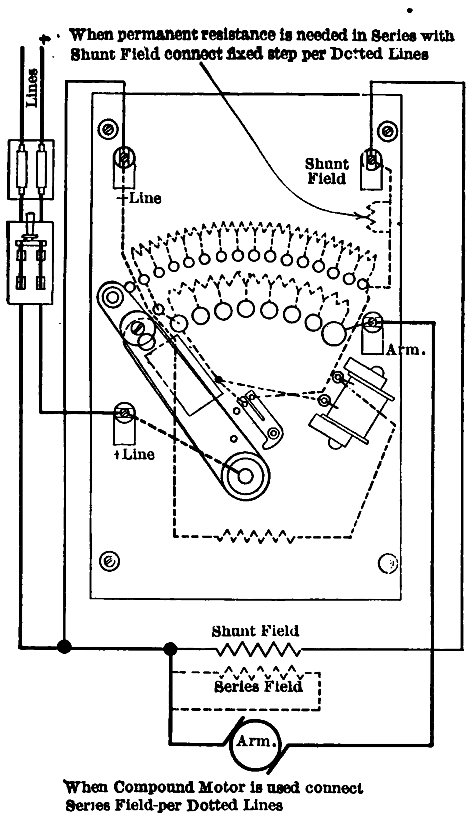

FIG. 49B.—Connection diagram for starter shown in FIG. 49A.

latches. In front of each switch is placed a pivoted metal stop so arranged as to prevent any of the switches being closed until the switch next to it on the left has been previously closed.

FIG. 50.—Multiple switch starting rheostat.

For machine tool equipments it is very desirable to locate the controller handle in close proximity to the normal position of the operator. If it is not convenient to locate the controller proper in

such a position the handle can be connected to it by an arrangement similar to that shown in Fig. 51.

The protective devices should receive careful consideration. In general, for motors that operate under widely varying load conditions or where overloads are frequent, circuit breakers should be chosen in preference to fuses. Circuit breakers

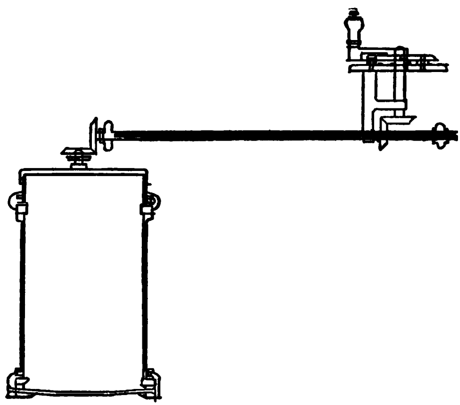

FIG. 51.—Arrangement for operating a machine tool controller from the tool carriage of a lathe.

equipped with a time-limit device are used for the protection of large motors that are subjected to overloads of momentary duration, too short to injure the motor, but which would cause a frequent annoyance by opening an ordinary circuit breaker. As an example we give below a description of the time limit feature of a circuit breaker made by the Cutter Company. The cylindrical vessel immedi-

ately below the housing contains a seat for a circular disk which is suspended from the armature coöperating with the restraining latch. The engaging faces of the disk and its seat are accurately surfaced and the disk is supported in such a manner that it may perfectly align itself with its seat. The disk when

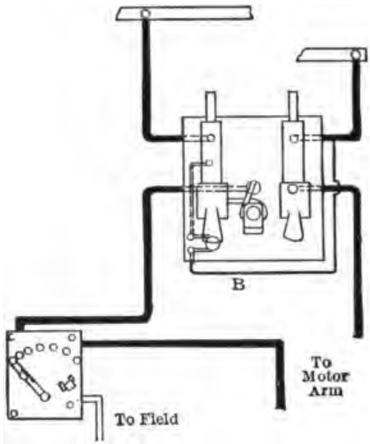

FIG. 52.—Connection diagram of an overload and no voltage release circuit breaker.

seated is surrounded with a shallow bath of specially prepared oil serving to exclude air from between the engaging faces, which are thus separated only by a thin film of oil. It is obvious that the intimate engagement of the disk with its seat causes an additional restraint upon the armature, proportional to the total pressure of the atmosphere and the disk.

In the event of overload, the pull of the armature communicated to the disk causes gradual extension of the oil film, until if the overload is sufficiently long continued, the film is finally ruptured, the disk is suddenly released and the armature, which now moves forward without restraint, causes the opening of the circuit breaker in the usual manner.

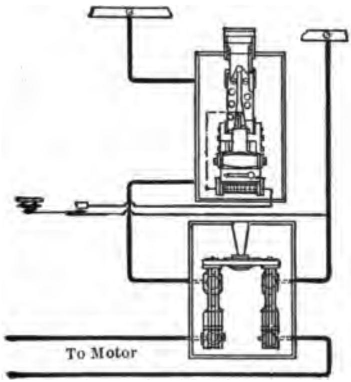

FIG. 53.—Circuit breaker equipped with an auxiliary shunt trip coil.

The seat may be turned by a small knob which moves over a scale upon which the relative time calibrations are indicated.

The connections of an overload and no-voltage release circuit breaker are shown in Fig. 52. A circuit breaker equipped with an auxiliary trip coil is shown in Fig. 53. This arrangement is very desirable for use where it is frequently necessary

to stop motors quickly, such as the operation of printing presses, thus eliminating the time necessary to reach the motor switch.

There are many applications where it is desirable to start and stop a motor from a distant point. The theoretical connections of a starting rheostat designed for such purposes are shown in

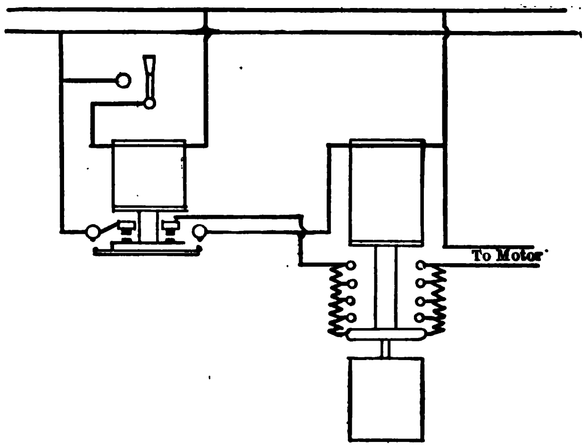

FIG. 54.—Theoretical connections for an automatic motor starter.

Fig. 54. Connections for this type of self-starter for use with motor driven pumps are shown in Figs. 55 and 56. For large motors in many kinds of service, where ordinary controllers would be too cumbersome or where the motor is necessarily controlled from a distance, a system for starting, stopping and reversing is very desirable. The

theoretical connections for starting and stopping service are shown in Fig. 57. The solenoids, it will be noted, are operated from an auxiliary circuit. The first one is energized by closing a small

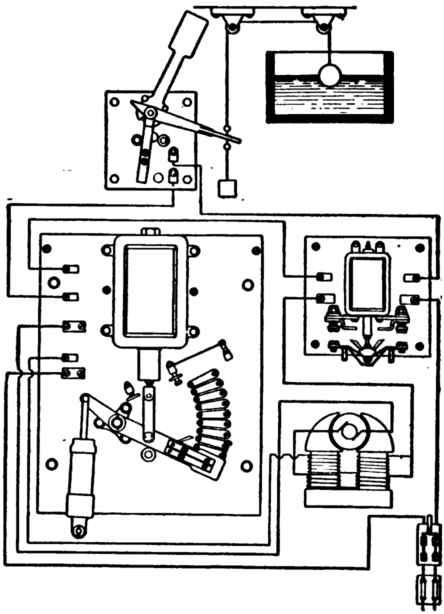

FIG. 55.—Self starter used with motor driven pumps. Open tank with float switch.

switch. The solenoid raises its contacts and connects the motor in circuit through a resistance, at the same time energizing the second solenoid whose contacts cut out one section of the re-

sistance, and connects the third solenoid to the auxiliary circuit and so on, accelerating the motor until it reaches full speed. Opening the small switch releases the solenoids and stops the motor. There are several types of control systems designed for various kinds of service.

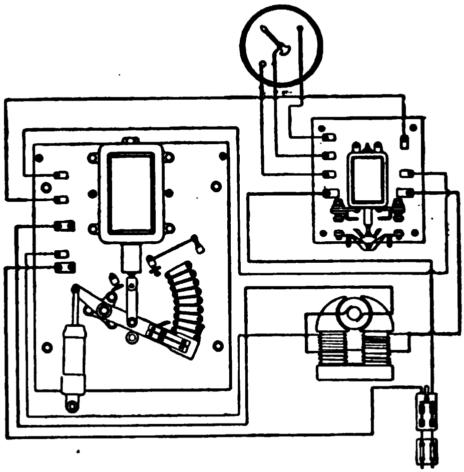

FIG. 56.—Self starter used with motor driven pumps. Compression tank with pressure regulator.

A Cutler-Hammer electric elevator controller is illustrated in Fig. 58. These controllers are especially designed for high speed elevator service. The elevator is controlled from the car by a car switch. A limit switch driven by the winding machine stops the elevator at the two limits of travel. The controller proper comprises a suit-

able self-starter main line switch, reverse switch, dynamic brake switch and relays. Self starters for the smaller sizes are of the sliding contact type, as shown in the illustration, but for the larger sizes they are of the multiple solenoid type. The self-starter controls resistance in the armature circuit for accelerating, and in addition is arranged

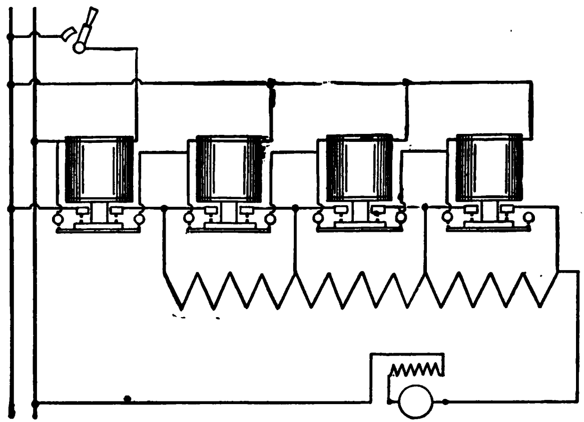

FIG. 57.—Theoretical connections of a motor control system.

to cut out the series field of the motor in the running position.

The Westinghouse system of control is of the switchboard type and consists of a series of electrically operated unit switches compactly mounted on a slate panel, as shown in Fig. 59, and controlled by a master switch. This switch can be located at any distance from the motor and can be operated

by hand or by any mechanical or automatic attachment. These controllers are suitable for 110, 220 and 550 volt circuits.

The acceleration of the motor operated on this

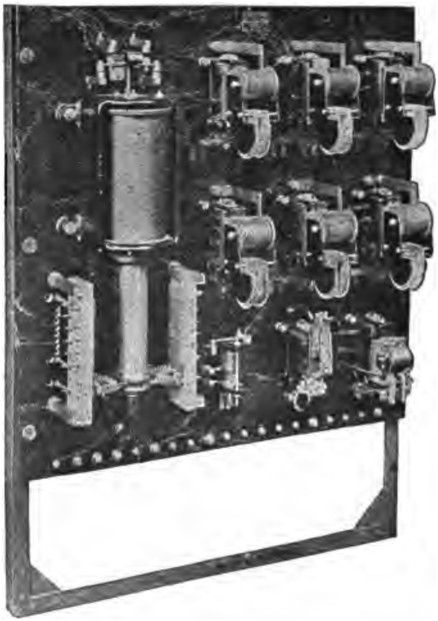

FIG. 58.—Electric elevator controller.

system is automatic and depends on the current. The switches are interlocked so that if any one is closed, the switch next succeeding cannot be operated until the current has been reduced to a predetermined value. Four switches are employed

to reverse the motor, two being used for each direction of rotation. Controllers of this type may be used with series, shunt or compound-wound motors. The method of control is rheostatic. The resistance can be proportioned for

FIG. 59.—Automatic control panel for mill table service.

starting service only, or for operation of the motor at any speed within its range by either field or armature methods. The number of steps in the armature resistance depends on the number of unit switches. These may be provided in any number to give the required regulation.

Under suitable conditions the controller may be arranged to close through a resistance so that it acts as a dynamic brake to assist in stopping the motor. If frequent reversals are required the controller can be arranged so that the resistance is inserted in the motor circuit before the reversing switch is opened, thus preventing excessive plugging of the motor, or, if a dynamic brake is used the reversing switch can be kept from operating until the motor has come approximately to rest.

Two types of master switches are commonly used. One has two notches in each direction, the first notch starting the motor with all the resistance in circuit and the second allowing it to accelerate to full speed. This arrangement is intended for starting service only and is well adapted to the operation of heavy rolls, elevators and other machines which impose severe starting conditions on the motor.

The other form of master switch is so arranged that the motor is started with all the resistance in circuit and the unit switches, which cut out several portions of the resistance, are so connected to the successive notches of the master controller that the motor may be operated on any notch, giving a speed variation by armature resistance. Acceleration is always automatic after the handle of the master switch has been turned to the desired notch. This type of master switch can be connected with a drum controller in such a way

that speed control by armature resistance can be employed.

The General Electric Company's Type M control system has been successfully employed in the control of large hoists, ore bridges, multiple printing presses, etc. It consists essentially of a num-

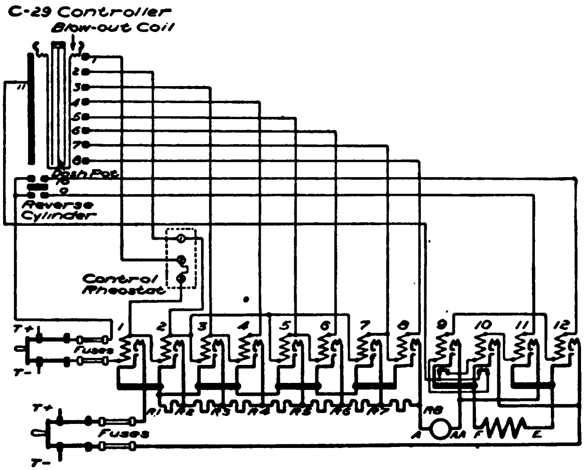

FIG. 60.—Wiring diagram of a G. E. type M control for one motor.

ber of electrically operated switches called contactors, that close the various power and motor circuits. These controllers are in turn actuated by a small master controller which has only to carry the current for actuating the contactor coils.

The contactors are of simple and substantial design and being provided with heavy and effec-

tive magnetic blowout, are capable of handling currents far in excess of those normally required. The master controllers are small, compact and easily operated and are provided with interlocking handles. A wiring diagram of a type M control is shown in Fig. 60.

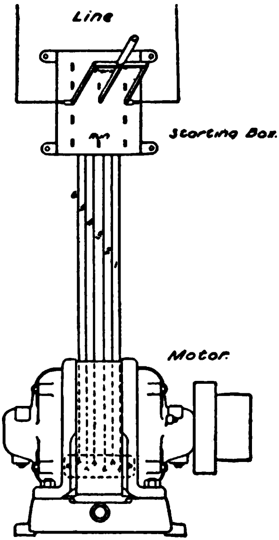

FIG. 61.—Connections of single-phase induction motor to starting box.

The control apparatus for direct-current systems has been considered so far. Appliances for controlling alternating-current motors differ considerably in principle and detail.

Figs. 61 and 62 show the connections of the General Electric Company's starting devices for single-phase motors.

For starting two and three-phase induction motors, the resistance used for starting direct-current motors is replaced by coils of insulated copper wire wound on laminated iron cores. The coils have several taps as shown in Fig. 63. In two-phase starters these coils are connected, one to each phase similar to the primaries of transformers. As the starting switch is turned the motor is connected successively to the various

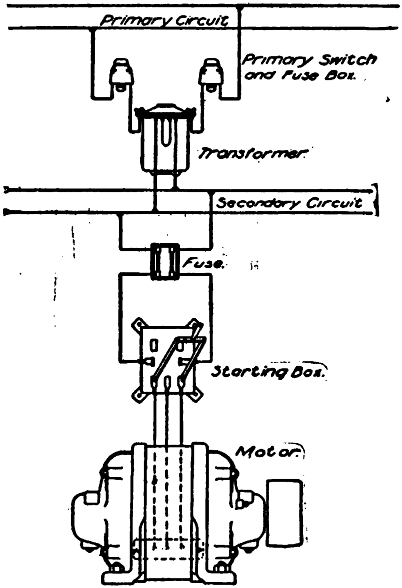

FIG. 62.—External connections of a single-phase induction motor.

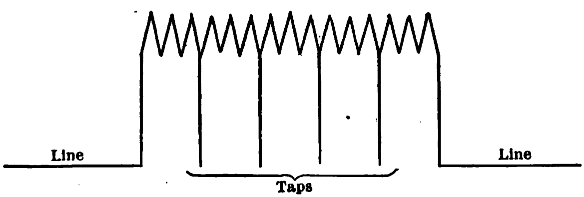

FIG. 63.—Theoretical explanation of starting devices for induction motors, two or three-phase.

taps, each step reducing the number of turns in circuit with the motor until it is connected directly across the line. In a three-phase starter the two coils are connected between the three phases similar to the primaries of two transformers connected for three-phase distribution.

FIG. 64.—Oil immersed auto-starter.

One type of Westinghouse auto-starter for constant speed induction motors up to 50 h.p. is shown in Fig. 64. It is a self contained unit, the auto-transformer and starting switch being in the same case. The lower part of the case forms a tank which is filled with oil for submerging the contacts

of the switch. The connections are shown in Fig. 65.

For large motors the controller or starting switch is generally separate from the autotransformer. Such a controller is shown in Fig. 66.

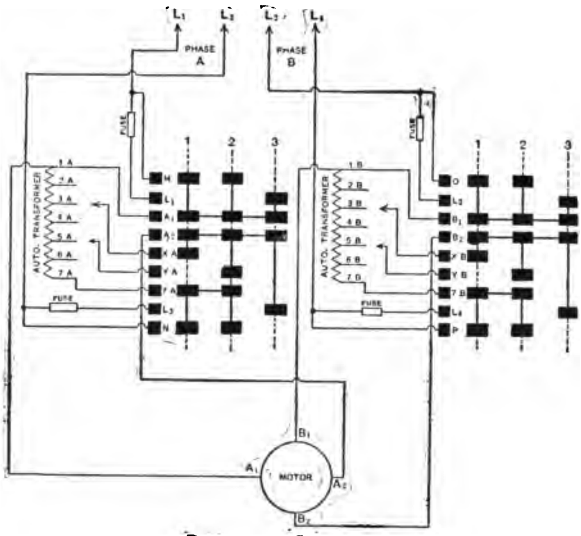

DIAGRAM OF CONNECTIONS

FIG. 65.—Diagram of connections for an oil immersed autostarter for constant speed induction motors.

The casing forms an oil tank which can be lowered for inspecting the working parts. Figs. 67, 68, 69 and 70 show the connections of several types of Westinghouse autostarters.

A General Electric starting compensator is shown in Fig. 71 and the connections of various

types in Figs. 72 to 75 inclusive. The connections of an Allis-Chalmers two-phase and a three-phase starter are illustrated in Figs. 76 and 77.

Self starters are frequently employed for starting alternating-current motors. These self starters are designed for use with two and three-phase motors. For two-phase alternating-current systems the primary circuit to the motor is controlled

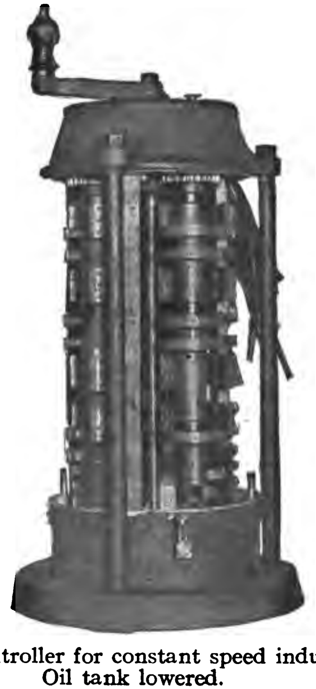

FIG. 66.—Controller for constant speed induction motors. Oil tank lowered.

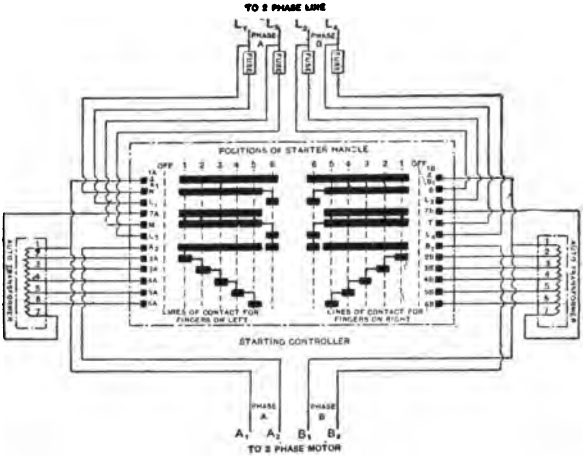

FIG. 67.—Diagram of connections for autostarter for constant speed induction motors 75 up to 150 h.p. at 400 and 500 volts.

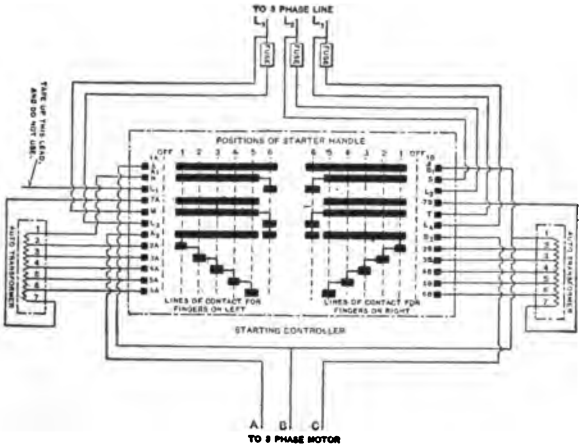

FIG. 68.—Diagram of connection for autostarter for constant speed induction motors 75 up to 100 h.p. at 200 volts.

by a single-pole switch in each phase circuit. For three-phase systems, the primary circuit of the motor is controlled by a switch in two of the three phases, the other phase being connected to the motor through one arm of the rheostat lever.

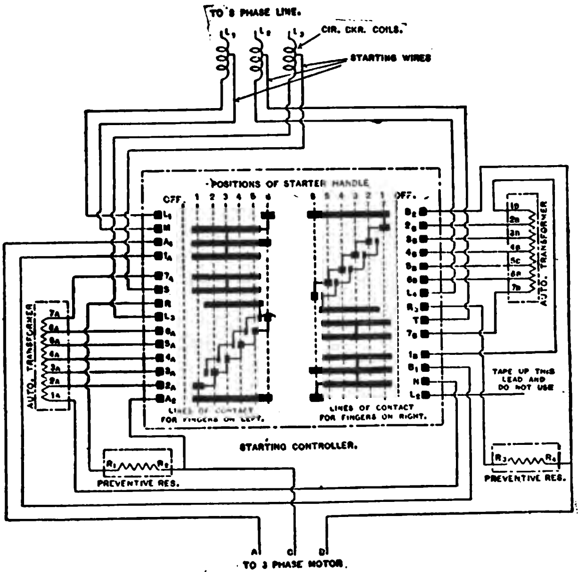

FIG. 69.—Diagram of connections for autostarter for constant speed induction motors 50 to 150 h.p. at 1000 to 6000 volts.

The self starter consists of a slate panel, containing a double-pole oil-immersed solenoid-operated line switch, a commutator and a resistance, a device for moving the rheostat lever, and a sole-

noid for the control of this device. It may be controlled by a pressure regulator or float switch, depending on the system used. For compression tank systems, a pressure regulator is used, and the

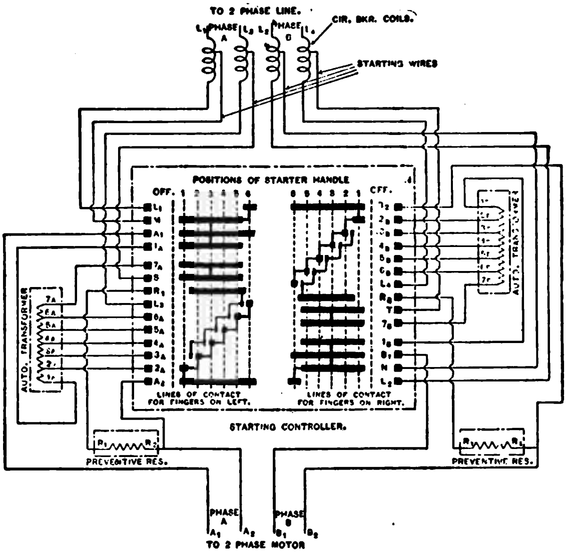

FIG. 70.—Diagram of connections for autostarter for constant speed induction motors 50 to 150 h.p., 1000 to 6000 volts.

motor is stopped and started at the two limits of pressure for which the regulator is adjusted. For open tank systems, the float switch is used, and the motor is stopped and started with the variation of the water level in the tank. The motor

is started by closing the line switch, which closes the primary circuit to the motor, through the starting resistance, and thereafter the mechanical device operates to cut the starting resistance out of circuit and bring the motor up to speed. The

FIG. 71.—Starting compensator for induction motor.

motor is stopped by the opening of the main line switch, and thereafter the rheostat is automatically returned to the starting position, in readiness for starting the second time.

The connections for an overload and no-voltage

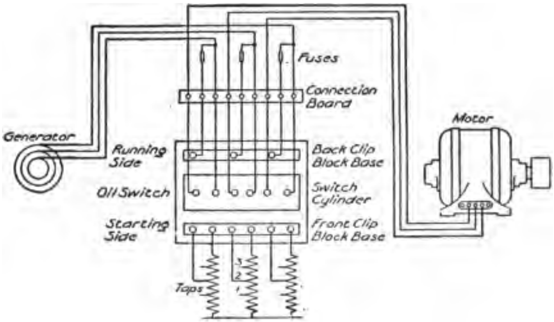

FIG. 72.—Diagram of connections of three-phase induction motor and starting compensator.

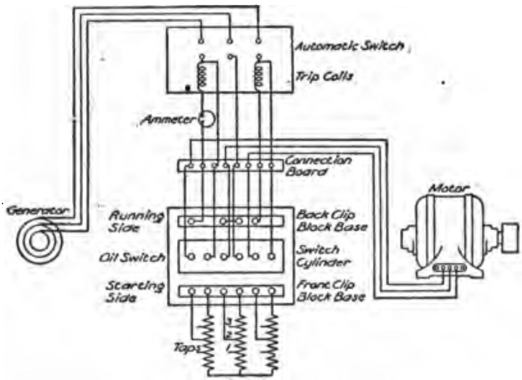

FIG. 73.—Diagram of connections of three-phase induction motor and starting compensator with automatic switch.

circuit breaker for the protection of a three-phase induction motor are shown in Fig. 78.

The circuit breaker terminals A and B are con-

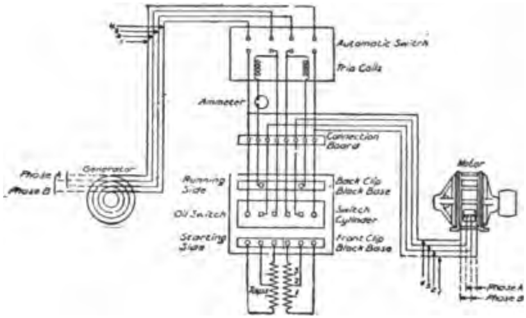

FIG. 74.—Diagram of connections of quarter-phase induction motor and starting compensator with automatic switch.

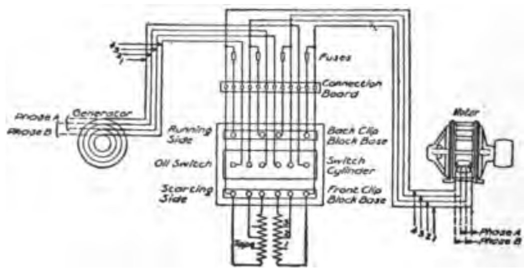

FIG. 75.—Diagram of connections of quarter-phase induction motor and starting compensator.

nected to small spring contacts, as shown, for a three-wire system two or three-phase. The terminal C is connected to the remaining lead of the

circuit and *D* is a common terminal for all no-voltage coils and has no external connection. The

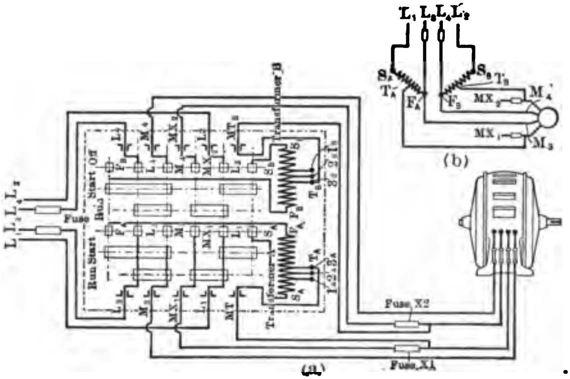

FIG. 76.—Two-phase potential starter.

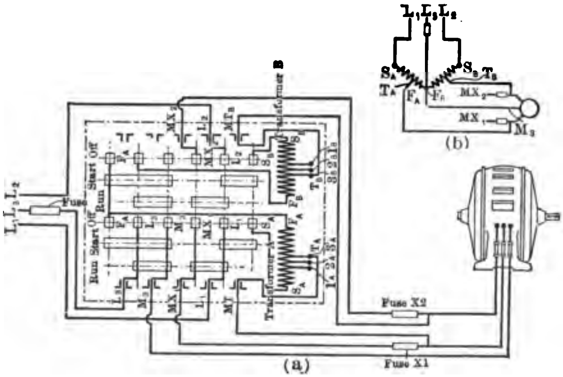

FIG. 77.—Three-phase potential starter.

circuit breaker should be so located that the no-voltage coils will be subjected to the full voltage of the circuit irrespective of the position of the

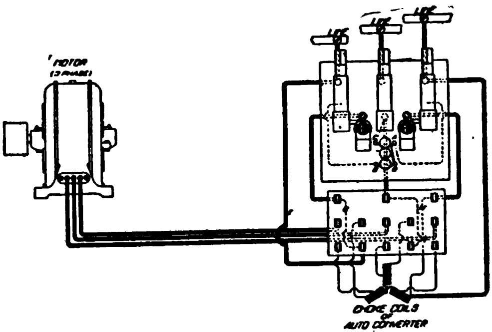

FIG. 78.—Overload and no-voltage circuit breaker for the protection of a three-phase motor.

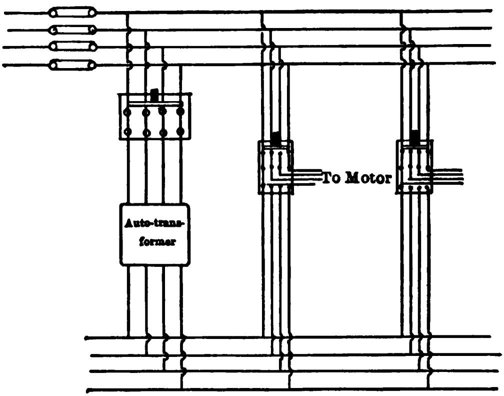

FIG. 79.—Method of controlling several motors from a single auto transformer.

starter. When it is desired to have the overload feature of the circuit breaker inoperative with the starter in the starting position, the usual connections *G* and *H* within the starter are removed and special connections *E* and *F* made.

Under some conditions of service it is desirable to start several motors from the same auto transformer. This may occur when there are several motors grouped in a comparatively small space. Fig. 79 shows the connections of such an arrangement for a two-phase system. This method is, however, equally applicable to three-phase systems. To start the motors the main switch, shown over the auto-transformer, is first closed. Then the double-throw motor switches are closed in the lower or starting position until the motor accelerates, when they are thrown up to the running position. This operation is repeated for each motor one at a time, after which the main switch is opened. To stop the motors the individual motor switches are opened.

CHAPTER IV.

MOTOR-GENERATOR SETS.

The great variety of operations now being performed by electrical machinery taking power from a single central station has created a demand for many forms of translating devices designed to transform the current of the transmission or distribution system to that best suited to a particular application. Among the important forms of transforming apparatus belongs that class of electrical machinery known as motor-generator sets. The changes affected by these machines are exceedingly numerous. They may be utilized to pass from one system of electrical distribution to another, to transform the voltage without change in form of the current or to change the frequency of an alternating current; they may be used as potential regulators, to equalize the loads between the sides of a three-wire system and in many other ways. The motors may be wound for operation from circuits of any commercial form and the generators to supply either alternating or direct current at a constant or variable e.m.f. Motor-generator sets are made in almost every possible combination of alternating and direct-current machinery, the more important forms including apparatus for the transformation and regulation of voltage, booster sets, charging outfits for storage

batteries, balancing sets for multi-voltage systems and frequency changers.

The motor-generator is the only practical voltage transformer for direct current and is one of its simplest applications. The machines are supported on a common base with armatures mounted on the same shaft, one wound for the voltage of the line, the other for the voltage and current required. Such sets are often used to secure a proper voltage for arc and incandescent lighting and charging storage batteries where the only available mains are those of a street railway system.

Another important application is found in industrial establishments where central station current has been adopted to take the place of a private plant or to supplement its service. Very frequently the voltage of the central station is different from that of a private plant. Under such circumstances a motor-generator set is installed to furnish the proper voltage for the motors and lamps. Fig. 80 shows a combination for service under similar conditions.

While alternating current is now generally adopted for the transmission and distribution of power and can be utilized in most electrical operations, there are a few classes of service which can be more advantageously performed by direct current. The motor-generator offers an easy mode of transformation from one system to the other. Any form of direct-current generator may

be coupled to an alternating-current motor and operated from the lines of any alternating-current transmission system. By this means storage batteries may be charged, electrolytic work performed, railways operated and direct current se-

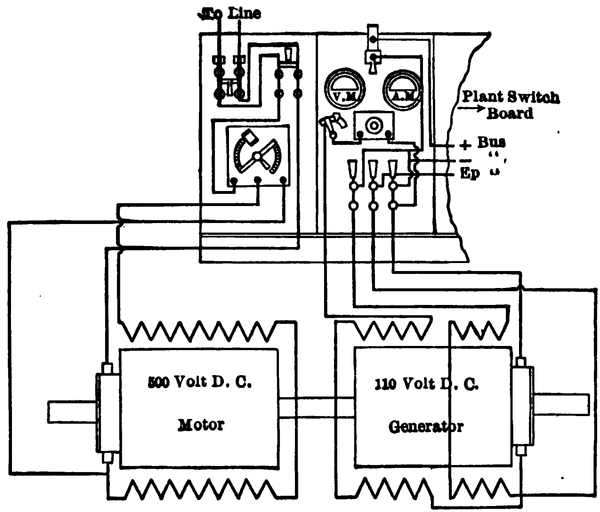

FIG. 80.—Diagram of connections for a motor-generator set.

cured whenever desirable, although distribution is made by the alternating-current system.

The driving motor may be of the induction or synchronous type. As the former is a simpler piece of machinery, is more easily operated and requires less attention, it is generally to be preferred. There are, however, conditions which

may be met with great advantage by the use of a synchronous motor.

A motor-generator may be substituted for a synchronous converter and in some classes of service possesses certain advantages. With a motor-generator set there are no electrical connections between the two sides of the system, an independent voltage adjustment is possible over a wide range and the regulation is not affected by fluctuations in the supply circuit. The choice between a synchronous converter and a motor-generator set should be largely determined by local conditions. Motor-generator sets composed of alternating-current motors and direct-current generators are largely used as exciter units in central stations.

Any form of alternating-current generator may likewise be connected to a direct-current motor and an economical means thus provided for transmitting power from direct-current stations to a distance beyond the range of direct-current voltage.

Motor-generators may be employed to secure a variable voltage from a constant potential system. Such a device has sometimes been used to provide a wide range of speed variations in motor operation, the generator of the set supplying a variable e.m.f. at the terminals of the motor armature, the motor field being excited at the full voltage of the line. While convenient and easy to control, this method is costly to install and operate. The great majority of motor operations which require a variable speed may be more simply handled by

the use of a three-wire balanced voltage or a single-voltage system.

A motor-generator booster set may consist of an alternating or direct-current motor coupled to a direct-current series-wound generator so designed that its voltage is proportional to the current in the field. When connected in series with a circuit fed from constant-potential generators it is evident that the booster will produce an increase in the voltage proportional to the current through the circuit. In this way the drop in a long line may be compensated and constant potential maintained at the far end of the circuit. Boosters of this type are frequently employed in street railway service to steady the voltage delivered to the cars and prevent the variations caused by a fluctuating load. With ordinary series boosters, effective overload and reverse current protection should be provided to insure the apparatus against reversal and racing in the event of the failure of its driving motor or of the main supply of current. The large and increasing use of storage batteries has opened up a new field of usefulness for the motor-driven booster. A battery is often "floated" on the line of a direct-current distributing system and charged through the regular feeder circuits during hours of light load by means of a properly adjusted booster. For such service the booster generator may be either shunt or differentially wound. A shunt-wound booster requires adjustment to keep the

charging of the battery at the proper rate. Differential windings have been developed so proportioned that, up to a certain load, the line voltage is raised by the booster so as to charge the battery, while at higher loads the battery, assisted by the booster, will discharge into the line, the whole operation being automatic.

Simple motor-driven generators are used to a considerable extent to charge storage batteries

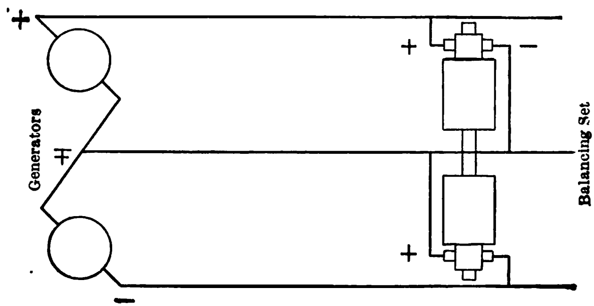

FIG. 81.—Diagram of a motor-generator balancing set.

for many purposes including the lighting of dwellings, performing electrolytic work, for the telegraph or telephone, the operation of automobiles, locomotives and many other types of apparatus.

To maintain an equal voltage on the two sides of a three-wire system two direct-current machines coupled together with armatures connected in series are frequently employed, forming a motor-generator balancing set as shown in Fig. 81. The

voltage of each machine is equal to that between the neutral and outside wires of the system. The two armatures are connected between the outside lines, while the mid-point is connected to the neutral wire. When the loads on the two sides of the system are equal, the motor-generator set simply revolves, performing practically no work; but when the load on one side of the system exceeds that on the other, the machine on the heavily loaded side acts as a generator, being driven by the other machine which acts as a motor, taking current from the lightly loaded side. In this way a balance is always maintained.

CHAPTER V.

INSTALLATION OF ELECTRIC MOTORS.

The installation of electric motors is a matter that should be thoroughly planned, and receive as much attention as the equipment itself. The successful operation and efficiency of an electric plant may be greatly impaired by poor wiring and auxiliaries, therefore, careful consideration should be given to this part of the work. In general, it is advisable to run separate circuits for each floor of a building or for each department if it is of considerable size. With this type of construction an accident to one feeder will not in any way interfere with the other circuits. Furthermore, if one main feeder with branches is employed, either the size of the conductors must be greatly in excess of that required at the outset, or in making extensions to the motor load the feeders will be overloaded, the drop in voltage will increase and the efficiency will be lowered. When a separate feeder system is used, additional feeders can be installed at any time to provide for additional requirements.

The wiring should be carried on the ceiling as far as possible. The motors mounted on the floor immediately above can then be connected without running wires down side walls or posts. This arrangement of wiring is also well adapted to

supplying wall and ceiling mounted motors adjacent to the feeders. Wiring supplying current to motors on the ground floor should be run in conduits in the basement. The rules of the Board of Fire Underwriters should be closely adhered to and the requirements of the inspection department having jurisdiction in the locality should be followed.

A well arranged entrance and distribution box

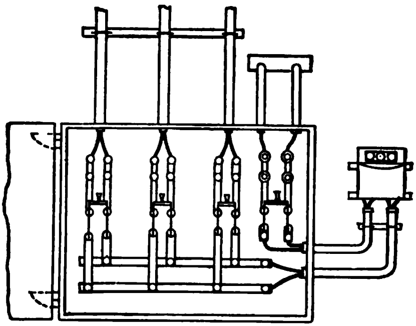

FIG. 82.—Entrance and distribution box.

_s shown in Fig. 82. The box is made of cast iron and the switches are mounted on a slate tablet fastened in the interior. The entrance switch and the main fuses are shown at the right-hand side. The smaller switches control the feeders for the various floors or departments. A service entrance is shown in Fig. 83 equipped with a Crouse-Hinds Type F Condulet shown in Fig. 84. A distribution box for the circuits of a building

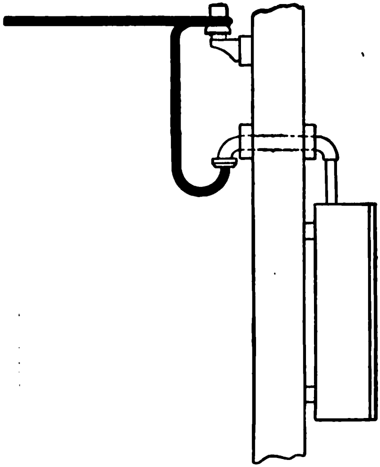

FIG. 83.—Service entrance equipped with type F condulets

FIG. 84.—Type F condulets for service entrance wires.

is shown in Fig. 85. For finished interiors a switch cabinet and panel board shown in Fig. 86 forms an attractive and serviceable combination.

Cast iron distribution and service boxes are the most desirable as they are more rigid and are

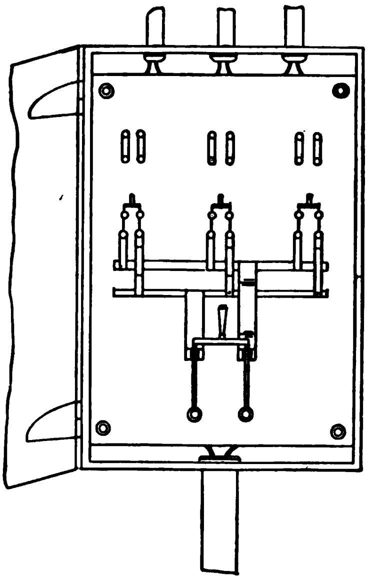

FIG. 85.—Distribution box.

fire proof. Such boxes should be lined with asbestos at least one-eighth inch in thickness well glued in place. Slate boxes or tablets should be used for holding the switches and fuses.

Suitable boxes conforming to the Underwriters'

rules can be made from well seasoned wood thoroughly impregnated inside and out with a moisture resisting compound and lined with sheet asbestos the same as the iron box.

FIG. 86.—Switch cabinet and panel board.

The general layout of wiring for a manufacturing building is illustrated in Fig. 87. It shows the general scheme of wiring already described. Where it is necessary to run wires over a post or

side wall, they should be protected by a pipe to a height of about six or seven feet from the floor as shown in Fig. 88. Fig. 89 shows how wires are run over the rafters of an ordinary ceiling. A well installed ceiling motor is shown in Fig. 90, and a motor mounted on the floor and fed from overhead wiring in Fig. 91. The Type A Crouse-

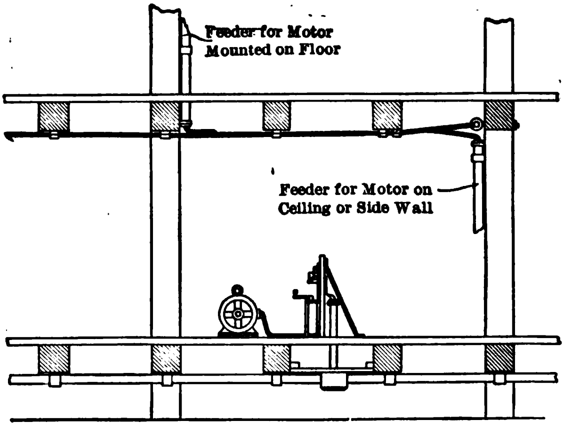

FIG. 87.—Layout of wiring for a manufacturing building.

Hinds Condulets shown in Fig. 92 make excellent outlets for the ends of conduits at the motor and controlling apparatus. These are made for both two and three-wire systems.

In erecting the motors it is very important that the location of the motor be wisely chosen. If direct connected and mounted on a machine the location of the motor is, of course, determined

by the location of the driven mechanism. In almost every case it is possible to select a location, which should be well lighted, dry, cool and as free from dust as possible. Safety in starting and stopping the motor requires that it be located where it is in sight of the starting panel or controller from which it is operated. It will not be difficult in a well planned factory or machine shop to find a spot which will combine all the advantages of location, but if the demands of service necessitate a particular location, some of the foregoing points may safely be varied if the machine be kept clean and dry.

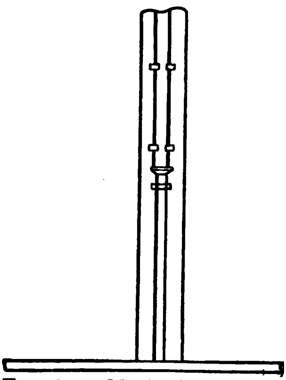

FIG. 88.—Method of running wires over a post or side wall.

To prevent vibration when running, the machine should be mounted on a substantial foundation; solid masonry makes the best foundation, but a frame work of timber may be used if the machine is not too heavy.

When the motor is set upon its foundation it should be carefully leveled and the shaft and pulley lined up with the driven shaft or pulley. In lining up two pulleys, the shafts should be parallel and the pulleys directly opposite. Before fastening the machine to its foundation, the

driving and driven pulleys should be lined up as carefully as possible, the belt put on and run slowly to make sure that the motor is properly placed. If the shafts are parallel but the pulleys

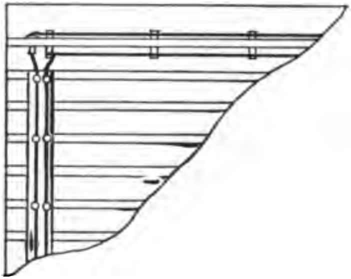

FIG. 89.—Wires running over the rafters of an ordinary ceiling.

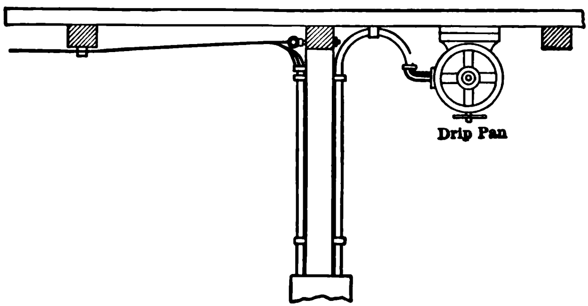

FIG. 90.—Ceiling motors.

not directly opposite, the belt will run more to one side than the other of the larger pulley; if the pulleys are opposite and the shafts not parallel, the belt will run to one side of the smaller pulley.

It is important to remember that the speed of a series-wound motor will increase indefinitely as the load is decreased and may become excessive so as to endanger the armature. For this reason it is not generally advisable to connect series-wound motors to their work by belts. When belts must be used they should be wider than required

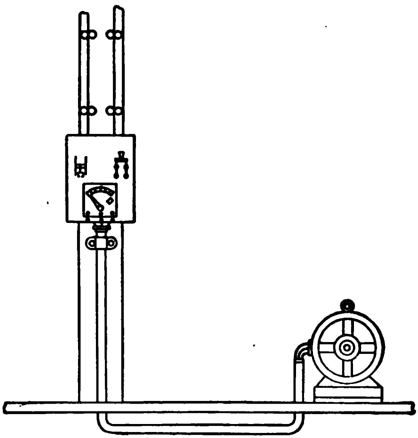

FIG. 91.—Motor mounted on floor and fed from overhead wiring.

by ordinary practice. The belts must be tight enough to run without slipping but the tension should not be too great or the bearings will heat. Belts should be run with, not against the lapping. Joints should be dressed smooth, so that there will be no jarring as they pass over the pulley.

When necessary to handle an armature care

should always be taken not to rely on the commutator for supporting any portion of the weight. Fig. 93 shows a proper method for lifting armatures.

Nearly all classes of motors, when the size is not prohibitive, are adapted to floor or wall mounting or ceiling suspension by either rotating the end brackets or the bearing housings through the requisite number of degrees to bring the bearing in the proper position. If, owing to the nature

FIG. 92.—Type A condulets.

of the machinery to be driven, an upright or vertical motor is essential, nearly all manufacturers can furnish their motors in this form. Direct-current motors may be obtained in the open, semi-enclosed and entirely enclosed forms.

For ordinary operating conditions where the motor is not subjected to undue moisture or flying particles of dirt or metal, the open motor may be used. When the motor is liable to injury from foreign material dropping into it, the semi-

enclosed motor should be used. Where excessive moisture or dust prevails, an entirely enclosed motor is best suited to the work.

In selecting a motor for running machinery, it often occurs that the pulley of the driven machine is of such diameter and the speed so slow that the standard speed motor of the power required by the machine cannot be used with its standard pulley. In such cases it is either necessary to select a larger frame motor to give the required

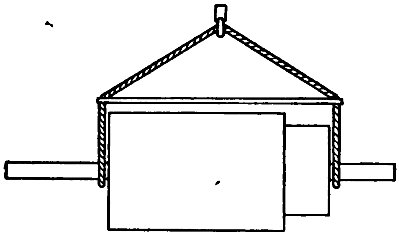

Fig. 93.—Proper method for lifting armatures.

power at a slower speed than standard or use a standard speed with a smaller pulley than ordinarily furnished. In order to keep down the speed of the belt it is then necessary to use an exceptionally small pulley. To avoid this a belt adjusting idler should be used. It consists of a swinging arm carrying a stud at its free end on which runs a self-oiling idler pulley, enabling a smaller pulley to be used than would otherwise be practicable. When the idler device is used it is customary to omit a sliding base. Under similar

conditions to the above if gearing is substituted for the belt and pulleys, the back geared motor with countershaft should be used.

Fan installations are frequently a source of trouble unless properly installed and the following suggestions are offered, which if followed will eliminate future difficulties. It is important that the size of the pulleys should be such that when the fan is operating at the maximum speed required, the motor will also be operating at the maximum speed for which it is designed, and will be taking a current not in excess of the full load capacity. These conditions are the only proper ones under which to operate and to meet which the rheostat is designed. If the arrangement of fan and motor is different from this, the rheostat will not operate properly in many instances.

It is commonly supposed that a rheostat is capable of reducing the speed of a motor to any extent desired, regardless of the load upon it. This is not correct, however, and cases have repeatedly arisen in which motor-driven fans have been installed, and on test it is found that the fan runs too fast when all the resistance is cut out. Attempt is then made to reduce this speed by cutting in resistance, and on the rheostat overheating under these conditions it is supposed to be insufficient in capacity.

Theoretically the power required to operate the fan varies as the cube of the speed. In motor-driven fans, however, the losses and disturbing

conditions which come in at lower speeds are such that the power will vary approximately as the square of the speed. That is, if a fan is running at a given speed and taking the normal current of the motor at this speed, there being no resistance in circuit, and the fan is then cut down one-half in speed by means of resistance, the power necessary to operate it at one-half speed will be approximately one-fourth, and under ordinary operating conditions the current will be one-half the full speed current, and one-half the e.m.f. will be dropped on the rheostat, the remainder being applied to the armature terminals. It will be clear, therefore, that if the motor is properly fitted to the fan, the rheostat should be so designed that the current is constantly decreasing as the resistance is cut in, reaching a minimum value of approximately one-half when the fan speed is reduced a like amount.

The standard fan regulator is not capable of controlling the speed of a motor driving more than one fan unless all the fans connected are in operation at the same time.

In the installation of alternating-current motors the transformers have to be considered. With a non-inductive load such as incandescent lamps the regulation of transformers is close, with an inductive load, the drop in potential between no load and full load is somewhat increased. If the motor load is large and fluctuating, and close lamp regulation is necessary, it is desirable to use

separate transformers for the motors. For the operation of induction motors from three-phase systems, either two or three transformers may be used. When a suitable size of transformer is available, however, three transformers are pre-

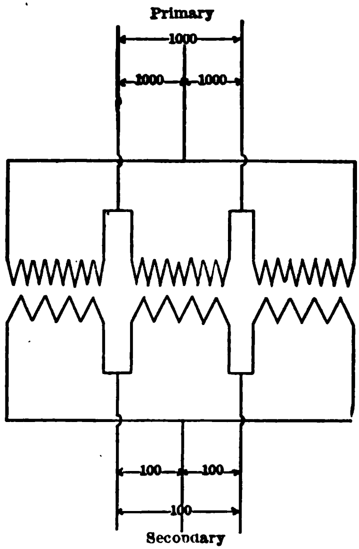

FIG. 94.—Delta to delta transformer connection.

ferable, since in this case each transformer acts as a reserve to the other two and thus provides for the operation of the motor even if one of the transformers becomes disabled.

For the larger motors the capacity of the transformers in kilowatts should equal the output of

the motors in horsepower. Thus a fifty horsepower motor requires fifty kilowatts in transformers. Small motors should be supplied with a somewhat larger transformer capacity, especially if, as is desirable, they are expected to run most of the time nearly at full load or even at slight overload.

The connections of three transformers, with their

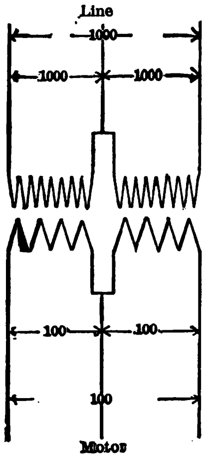

FIG. 95.—V-connection.

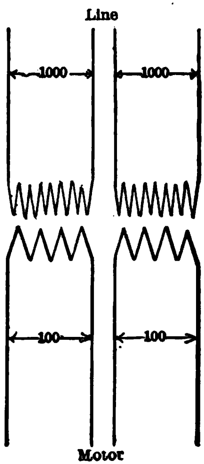

FIG. 96.—Two-phase, four-wire system.

primaries connected in delta to the generators and the secondaries connected in delta to the motor are shown in Fig. 94. The connections of two V-connected transformers for an induction motor operating on a three-phase circuit are shown in Fig. 95. It is identical with the arrangement shown in Fig. 94 except that one transformer is

omitted and the other two transformers are made correspondingly larger.

The copper required in any three-wire three-phase circuit for a given power and loss is 75 per cent of that necessary with two two-wire single-phase or a four-wire two-phase system having the same voltage between lines.

The connections of two transformers for supplying motors on the four-wire two-phase system are shown in Fig. 96. This system consists practically of two separate single-phase circuits, half the power being transmitted over each circuit

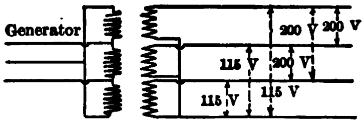

FIG. 97.—Connections of three transformers for low tension distribution by four-wire, three-phase system.

when the load is balanced. The copper required as compared with the three-phase system to transmit a given power with a given loss and voltage between the lines is 133⅓ per cent, that is, the same as with a single-phase system.

The connections of three transformers, for a low tension distribution by the four-wire three-phase system are shown in Fig. 97. The three transformers have their primaries joined in delta connection, and their secondaries in Y or star connection. The three upper lines are the three main three-phase lines, and the lowest line is the com-

mon neutral. The difference of potential between the main conductors is 200 volts, while that between either of them and the neutral is 115 volts $\left(115 = \frac{200}{1.73}\right)$, 200-volt motors are joined to the mains, while 115-volt lamps are connected between the mains and the neutral. The neutral is similar to that of the Edison three-wire system, and carries current only when the lamp load is unbalanced.

The potential between the main conductors should be used in calculating, and the section of

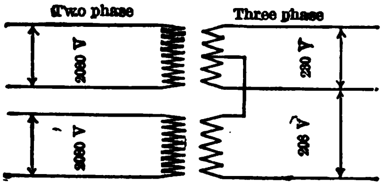

FIG. 98.—Three-phase motor operated from two-phase circuit.

the neutral wire should be made in the same proportion to each of the main conductors as the lighting load is to the total load. When lamps only are used, the neutral should be of the same size as the conductors. The copper then required in a four-wire three-phase system of secondary distribution to transmit a given power at a given loss is about 33⅓ per cent, as compared with a two-wire single-phase system or a four-wire system having the same voltage across the lamps.

Standard three-phase motors may be operated

from two-phase circuits by connecting a 9:1 transformer as shown in Fig. 98. While this does not give a true balanced three-phase secondary it is within 5 per cent. and sufficiently close for motor work. Care should be taken in selecting the proper size of transformer for changing from two-phase to three-phase as the main transformer is required to furnish 54 per cent of the total power, while the teaser transformer furnishes but 46 per cent of the total power. Each lead for a three-phase motor should be 58 per cent of each wire of a single-phase system based upon the same apparent kilowatt (kilovolt-ampere) capacity and voltage. Before starting the motor, the three secondary voltages should be tested by means of a voltmeter or incandescent lamp, to ascertain if the connections have been properly made, since with wrong connections excessive currents will burn out the transformer and possibly the motor.

CHAPTER VI.

OPERATING HINTS.

Before attempting to start a shunt or compound-wound motor, test out the field circuit to see that it is closed. This may be accomplished as follows: Remove the wire at the starting box from the terminal marked "Arm," and carefully insulate the end. Then close the main switch and bring the starting lever up to the running position and note whether the release magnet holds the lever. This shows whether or not the circuit is complete, since the magnet is in series with the field winding. Leaving the starting box in the above position go to the motor and, with a pair of pliers or a piece of iron, note whether the poles give a magnetic pull. In performing this operation be very careful not to touch the field terminal, thus grounding or short-circuiting the field winding. As a final or third test, slowly open the main switch, and if an arc results the circuit is complete. These tests should always be made before attempting to start up a motor the first time.

When these tests have been completed, see that the main switch is open and the starting lever at the off position, thus opening the circuit; then replace the terminal on the starting box.

In case the speed of a compound-wound motor

is above normal, the series field is probably opposing the shunt field. If sufficient starting resistance is at hand, the motor should be tried as a shunt and as a series motor. In the latter case do not attempt to bring the motor up to speed; but allow it to turn a few revolutions to see that it turns in the same direction that it does when running as a shunt motor. These tests should be made with no load on the motor and if found all right permanent connections can be made and the motor operated.

When a motor is put into operation always be sure that the connections are tight and the brushes in the proper position and never leave the starting box lever in an intermediate position. See that the oil wells are properly filled and when first starting rub the commutator occasionally with a cloth having a few drops of oil on it until the commutator obtains a dark gloss.

If sparking occurs move the brushes backward and forward until a point is found where no sparking occurs under normal load. It is advisable to change oil in the bearings two or three times in the first few days, after that the oil may be left in about three months, adding enough occasionally to make up for losses. The machine should be watched for the first few days to see that the brushes do not grind and that the oil rings revolve freely.

Keep the machine clean, dry and see that no bolts, nuts, screws, etc., are left around, as these

may be drawn into the motor when its field windings are excited and the machine running.

With belted machines see that the armature oscillates in its bearings while running under load, as this will greatly lengthen the life of both the commutator and the bearings.

Precaution should be taken never to break a field circuit suddenly, as the inductive discharge voltage is always many times higher than the operating voltage, and may puncture the field insulation. Further do not open a switch on a circuit carrying a large amount of current but trip the circuit breaker first, then open the main switch. See that all switches, circuit breakers, etc., are open when the motor is not in operation and always close the circuit breaker first, then close the switch.

Care should be taken in starting a motor that the handle of the starting box is not rotated too fast. Standard starting boxes for motors up to 20 hp. are designed to start the motor in not less than 15 seconds with approximately 50 per cent over full-load current. For motors above 20 hp. and up to 50 hp. 30 seconds should be allowed for starting with 50 per cent over full-load current, and for motors above 50 hp. and up to 100 hp. 45 seconds should be allowed. Where it is possible to do so the motors should be started up somewhat more slowly than the above as by so doing the current drawn from the line will be kept down to full load current or below. If the motor is

started more rapidly than is indicated above, flashing at the brushes may occur.

In stopping a motor, first open the circuit breaker or switch. This will cut in the resistance of the automatic stopping and starting rheostat. Never attempt to stop a motor by forcibly pulling open the starting rheostat. Disregard of these instructions may burn out the field coils. If the brushes have been properly adjusted they should not be moved when stopping and starting. The best position for the brushes is that which gives the best commutation at normal voltage for all loads. In no case should the brushes be set so far from the neutral point as to cause dangerous sparking at no load. Motors which are to be run in both directions under load should have the brushes set on the no-load neutral point.

The ends of all brushes should be fitted to the commutator so that they make contact over the whole surface. This can be done by putting each brush in its holder and grinding it with a piece of sand paper placed between the brush and the commutator until it fits the curvature of the commutator surface. If the brushes are copper plated, their edges should be slightly beveled, so that the copper does not come in contact with the commutator.

Armatures should be protected from both mechanical and electrical injury. The latter will be prevented by carefully following the instructions given in regard to starting and stopping the ma-

chine. The former will be prevented by locating the machine, as previously advised, in a clean place of even and moderate temperature. Moisture weakens insulation of coils and may cause them to become grounded on the frame, especially if the frame is not insulated from the ground.

The commutator is an important part of a motor and requires careful and intelligent attention. Wherever possible the entire care of the commutator and brushes should be assigned to a competent man who can be held responsible for their proper attention.

To keep a commutator clean, ordinarily it will only require a daily wiping off with a piece of canvas. Providing this is done regularly so as to keep the commutator surface and end free from dirt and oil, the commutator will, in the majority of cases require no other attention.

In service the ideal appearance of a commutator is a polished surface of dark brown color. Sand paper, sand stone or emery cloth should never be used on a commutator which is taking on a polish and shows no signs of roughness. Commutators which do not take on a polish and show signs of roughness should be smoothed off with a piece of sand paper, and if quite rough a piece of sand stone may be used.

Flat spots sometimes occur on commutators. They are usually caused by excessive wear, by too much end play, by a loose commutator, a bad belt splice or by a flash produced by a short cir-

cuit on the line. When a commutator becomes out of true it should be turned down.

A small amount of lubricant may be applied to the commutator. A lump of paraffin rubbed across the face once a day is sufficient. Lubricant should always be applied sparingly and never in sufficient quantities to collect on the surface and about the brushes and leave them in a gummy condition. Excessive noise from the brushes may frequently be remedied by the application of a small amount of lubricant.

A commutator bar which projects above the others may be detected by a jumping motion of the brush holder spring, by a pencil point held on the commutating surface, and in some cases by a short intermittent spark at the brushes. If the commutator is found to have a high bar, the armature should be removed and the commutator repaired.

For motors using oil and waste or grease as a lubricant, the following suggestions should be observed:

A high grade of wool waste should be used, as cotton or poor grades of wool waste become soggy and will not retain their position against the shaft. The waste must be thoroughly saturated with oil, and should be immersed for at least forty-eight hours and then allowed to drip on a rack for ten or twelve hours before using. If there is too much free oil it will be forced out into the drip pockets when the waste is packed in the

bearings, and will accumulate on the equipment or may work into the motor.

In general, a good quality of car journal oil should be used. The flow of oil is affected by the temperature, therefore a heavier grade should be used in summer and for motors operating in warm places, than for motors operating in cooler seasons and locations. In packing the bearings, care should be taken to see that the waste fills the entire pocket and fits closely against the shaft, but it should not be forced too tightly as the surplus oil will thereby be squeezed out.

If the motor is thoroughly overhauled at any time it is advisable to repack the bearings, or if they should run hot it is better to change the waste at once, as it is easily glazed over by particles of babbitt ground off the hot bearings. The frequency with which the oil is added depends upon the local conditions, and is best determined by experience, but it is better to use too much than too little.

As bearings lubricated with grease require more attention than those lubricated with oil, the grease should be kept clean and the grease pockets kept well filled. In filling the grease cups it is important to have all the parts adjacent to the cover free from dirt or grit, to prevent these from getting into the grease and spoiling the bearings. Inspections should be made at regular intervals, even if the bearings are running satisfactorily.

In the following paragraphs simple suggestions for locating motor troubles will be found.

To test for open circuit in an armature, first clean the commutator thoroughly and connect a voltmeter with a source of e.m.f. supply and two brushes diametrically opposite each other on the commutator as shown in Fig. 99. All leads should be disconnected from the brush holders and the brushes filed down so that they are narrower than the width of a segment. Rotate the armature by

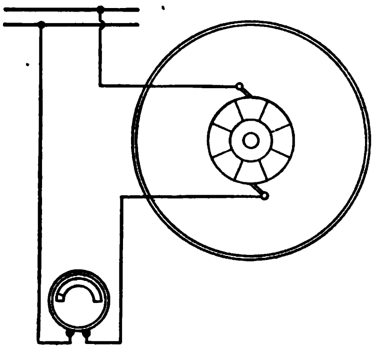

FIG. 99.—Test for open circuit in an armature.

hand and note the deflection of the voltmeter. When the needle falls back to zero it indicates that the trouble lies at either one or the other segments on which the brushes rest.

To test for open circuits in the coils, or short-circuits between segments remove the voltmeter and substitute an incandescent lamp as shown in Fig. 100. Next attach copper springs to a piece of wood, having one adjustable as shown

in Fig. 101, and connect them to an ordinary telephone receiver. To test for open circuit place the exploring brushes against two adjacent seg-

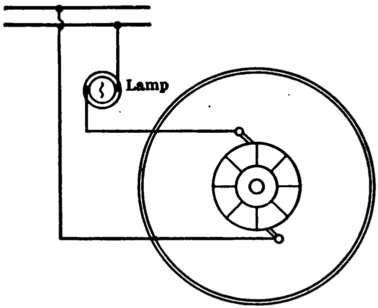

FIG. 100.—Test for open circuits in the coils or short circuits between segments.

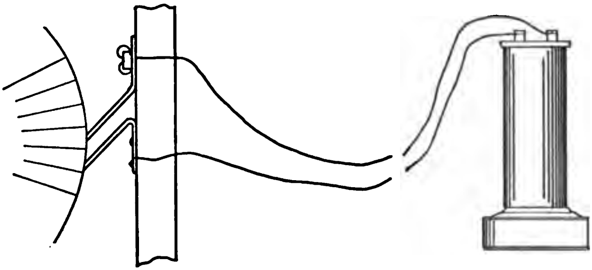

FIG. 101.—Test for open circuits in the coils or short circuits between segments.

ments as shown and revolve the armature as before, holding the telephone receiver to ear. A tick in the receiver will be heard as the brushes pass over the segments. If the noise suddenly in-

creases between any two bars it indicates a high resistance or break in the coil included between the two segments. When two adjacent segments become short-circuited, a bar to bar test will indicate the location of the trouble by the absence of a tick at the point of trouble.

To locate a short-circuit between two coils the brushes should be adjusted to include or straddle three commutator bars. The noise in the receiver will then be about twice as loud until the coils at fault are reached when the noise will diminish. When this occurs test each coil for trouble and if individually they are all right, the trouble is between the two. To locate a ground in the armature place one terminal of the receiver on the shaft or frame of the machine and attach the other to one of the brushes on the commutator, if there is any noise in the receiver it indicates a ground. Revolve the armature slowly and when a point is reached where the least noise is heard in the receiver, there will be found the grounded point. Care should be taken in making this test to keep the wiring of the test connections well insulated from the ground.

CHAPTER VII.

REPAIRS.

The economical operation of the repair shop and its ability quickly to execute the necessary repairs is a subject of importance to every industrial plant using electric power. The equipment of tools and labor saving devices, and the manner in which the work is systemized, are important factors upon which the ultimate success or failure of the repair work depends.

There are numerous small devices that are inexpensive and add greatly to the quality of the work and uniformity of the product. The shop equipment should include a lathe, shaper or planer, drill press, milling machine with an indexed head, a bake oven for the baking of armatures, field coils and commutators, a winding machine and numerous moulds for armature and field coils.

A convenient and serviceable oven is shown in Fig. 102. It is made of an angle-iron frame covered with sheet iron lagging and provided with a large door. Steam coils are arranged about the interior for maintaining the required temperature. In the figure a track is shown with a small car having an angle and channel-iron frame, and provided with notches for holding the armature shafts. When commutators or field coils are to be dried, a sheet of iron may be laid on the car

forming a table. The convenience of such arrangement will readily be appreciated as all heavy parts can be easily loaded and unloaded in the open by means of a crane or hoist.

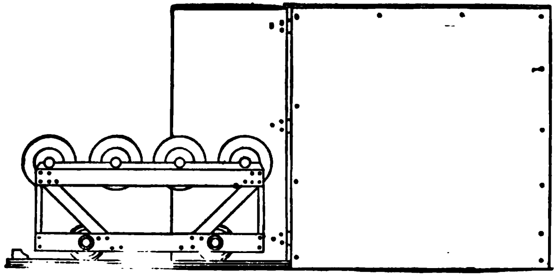

FIG. 102.—Oven for drying commutators and field coils.

A rack for storing extra armatures is shown in Fig. 103. This is easily made of timber, occupies little space, and permits the armatures to be readily removed when needed.

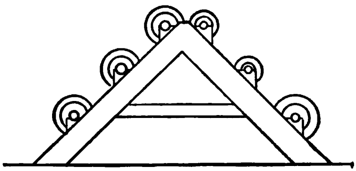

FIG. 103.—Rack for storing armatures.

The commutator is the part of the motor subjected to the greatest wear, therefore the facilities for quickly refilling them and making extras should be at hand. The first operation is to loosen the

armature leads and remove the old commutator. The segments should be bound tightly with heavy cord and the shell removed, when templates corresponding to the bore of each end should be made. Drop-forged segments for refilling can generally be purchased for the various standard motors. Old commutators, however, are frequently so far out of date that standard sizes of segments will not be suitable. A very good

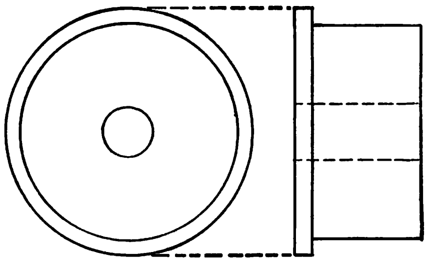

FIG. 104.—Copper casting for a commutator.

commutator can be made from a copper casting, similar in shape to the assembled commutator, that is, cylindrical in form and enough larger than the original to allow for finishing as shown in Fig. 104. Large castings may be cored out at the ends for collars, thus saving some stock and considerable labor. Bore out the rough casting and drive it on an arbor and place it in the centers of a milling machine. Use a $\frac{1}{16}$ inch saw about four or five inches in diameter; cut as many slots in the casting as there are to be segments. A casting with the slots partially cut is shown in Fig. 105.

By using an indexed head this is a very simple matter. Cut the slots to within about $\frac{1}{8}$ inch of through. Now drive out the arbor and catch the casting in a vise and finish cutting through the slots with a hack saw. Two blades put in the frame at the same time will make a cut about equal in width to that made by the saw in the milling machine. File off the burrs or irregularities that remain on the segments. As the segments are sawed up by a $\frac{1}{16}$ inch saw, and the insulation is only about $\frac{1}{32}$ inch in thickness, the rough casting must be made enough larger to allow for the difference. For instance, in sawing up a casting into 32 segments, two inches of the circumference would be wasted. Using $\frac{1}{32}$ inch insulation would make up for one inch only, so that the rough casting must be one inch greater in circumference—over and above stock allowed for finishing—than the original size of the commutator.

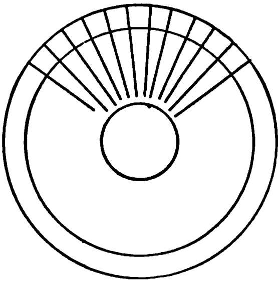

FIG. 105.—Casting with the slots partially cut.

Sheet micanite is desirable for insulation between the segments and pieces can easily be cut out with a pair of snips using one of the new segments as a pattern. To assemble the segments, stand them upright on a smooth surface with the insulation in place as shown at *b*, *c*, *d*, etc., in Fig.

106. They should then be clamped firmly in an iron or steel clamping ring with clamping screws shown at *h*, *i*, *j*, etc., which bear against curved pieces of metal, *e*, *f*, *g*, etc. The assembled segments are now ready for boring and should be clamped in the chuck of a lathe and bored at each

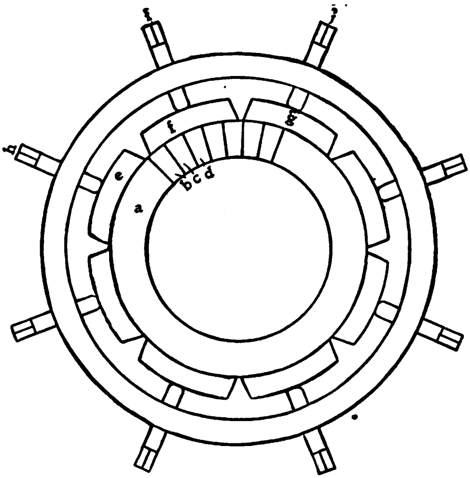

FIG. 106.—Clamp for holding assembled segments while machining.

end to correspond with the templates already prepared.

A device for holding the segments while finishing the outer surface is shown in Fig. 107. The segments are shown at *a* and *a'*, *b* is an arbor and *d* and *d'* are clamping nuts for holding the collars

c and c' in position. The temporary shell should be applied before loosening the outer clamp shown in Fig. 106. When in place the assembled segments can be turned and finished. They are then ready for the slots to receive the leads. For this the milling machine and the indexed head are used as before.

The segments should be carefully lined up as shown in Fig. 108 by sighting along the edge of a

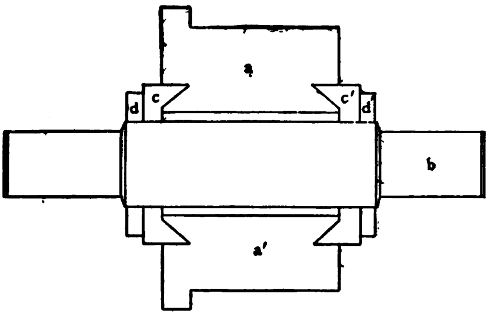

FIG. 107.—Device for holding the segments while finishing the outer surface.

try-square blade when it is easily determined whether each segment is in line. If any are twisted they should be driven into position by means of a small cold-chisel and hammer. The outside clamp should next be applied and the temporary shell removed when the segments are ready for assembling in the original shell. When removing the old segments care should be taken to keep the insulating rings at each end intact for

future use. After the new segments are assembled in the shell, the commutator should be placed in the oven until thoroughly heated and the shell again tightened. The commutator after a final polishing is then ready for use. Care should be taken in all the operations to see that no metal chips become imbedded in the insulation and

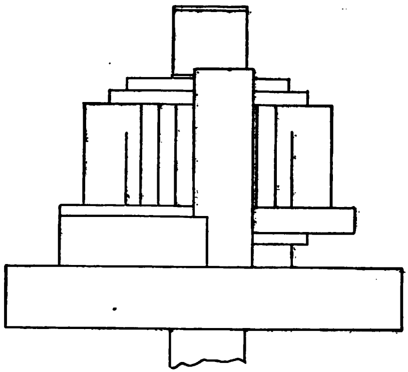

FIG. 108.—Method of showing if segments are in alignment.

before the commutator is used it should be thoroughly tested for grounds or short-circuits.

It is desirable when refilling a commutator to make up several assembled sets of segments ready for future use. This can be done by placing bands about the segments as shown in Fig. 109. The bands consist of brass wire wound tightly and held in place by clips and solder as shown.

The bands should be separated from the segments by heavy paper. A convenient arrangement for placing tension on the banding wire is shown in Fig. 110. It consists of two pieces of fiber *a* and *a′* with retaining pins *b*, held in the tool post of the lathe. Any tension desired can be obtained by means of the clamping screw.

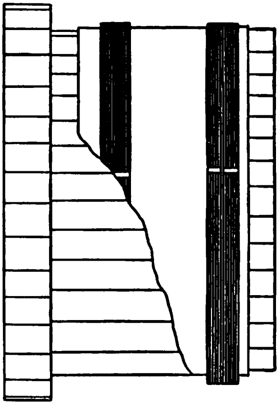

FIG. 109.—Finished segments secured by bands.

If the slots in the commutator for the armature leads are tinned before using, the soldering operation is much simplified. This can be done by applying soldering flux to the slots and immersing in melted tin.

The successful winding of armatures requires some skill and patience but can be successfully accomplished by the plant electrician with the aid of a few simple appliances. He should have at hand standards for holding the armature during the process of winding, one or two fiber mallets, some chisel shaped pieces of fiber for driving the wires into place and a good supply of insulating material.

A convenient and serviceable standard is illustrated in Fig. 111. It consists of a cast-iron base plate, an upright made of pipe, and a suitable

casting for supporting the two rollers. The armature shaft rests on the rollers which enables the armature to be turned freely. Many small devices and tools will suggest themselves to the electrician that will add to the convenience of the work.

In an old motor installation there are generally various types of old style motors having surface wound drum armatures and ring arma-

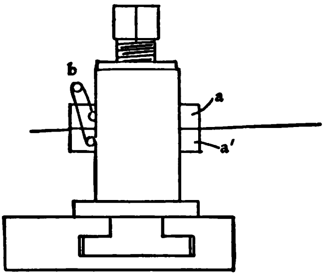

FIG. 110.—Method of placing tension on the banding wire.

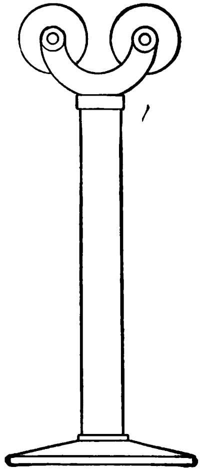

FIG. 111.—Standard for holding the armature during the process of winding.

tures. The winding of such armatures is, of course, all hand work, that is, the wire must be wound directly on the core instead of forming the coils separately as is the practice with modern machines.

Fig. 112 shows the smooth core drum armature in course of winding. The winding is begun at the commutator end between the pegs at 1, the

wire passing backward and over the rear end, forward on the opposite side of the core to the starting place and through the space 1′ to the place of beginning. This operation is repeated until the requisite number of layers are wound. The second coil begins at 2 and passes around through 2′ to the starting point. The third coil

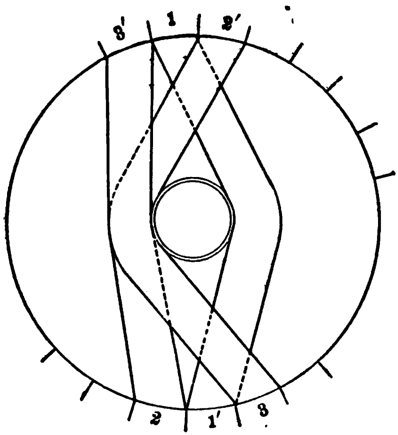

FIG. 112.—Smooth core drum armature in course of winding.

is wound through 3 and 3′ and so on until all are completed. By commencing each coil on the side opposite to the last succeeding coil, every second space will have coil ends and, consequently, the spaces between will be blank, that is, there will be no coil ends. In connecting the leads, the last end of one coil is connected to the beginning of

the coil in the second space removed. To illustrate, the end of coil 2 would be connected to the beginning of coil 3 and so on around the armature.

In winding ring armatures it is difficult to space

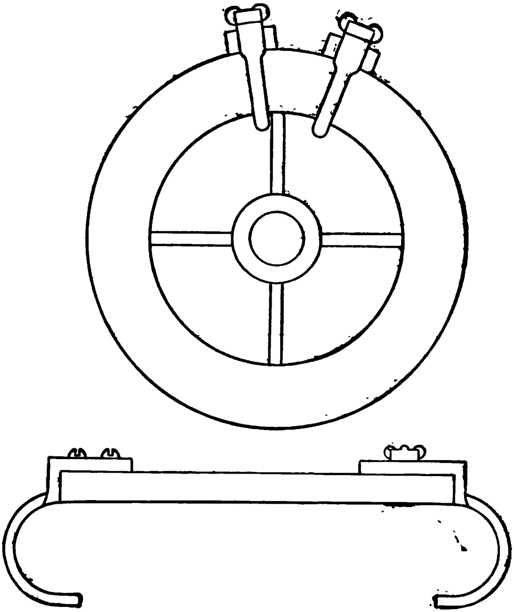

FIG. 113.—Guides to be used for winding ring armatures.

each coil accurately and keep it in position during the process of winding unless guides are used. Fig. 113 shows the manner of placing the guides in position. The lower sketch in the figure shows their construction.

One of the hooks is slotted lengthwise at the top and is held in position by the thumb nut. The slot permits the hook to be pulled outward to slip over the end of the armature when it is pressed back into position and clamped. The periphery of the armature can be spaced accurately by pasting a piece of light colored paper over the surface and drawing lines from end to end parallel to the shaft, a distance apart corresponding to

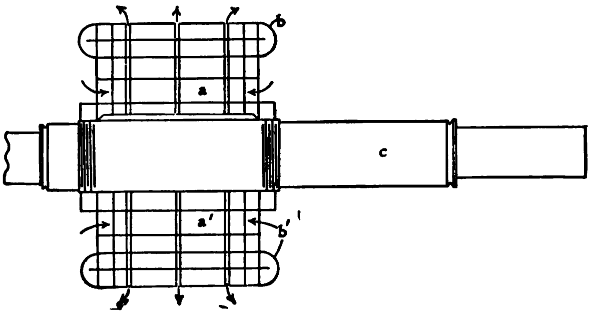

FIG. 114.—Modern ventilated drum armature.

the width of the coil. Unlike the drum armature, the ring type has two coil ends to each space. They are, however, connected in a similar manner to the drum armature, that is, the beginning of one coil is connected to the end of the coil next adjacent. The twisted ends form the leads which are soldered to the commutator bars. There are several modifications of these well known windings, that can be easily ascertained by carefully noting the connections when tearing a burned out arma-

ture apart. The modern slotted drum armature employs form-wound coils imbedded in the slots of a ventilated core as shown in Fig. 114 where *a* and *a'* are air ducts, *b* and *b'* the coils and *c* the

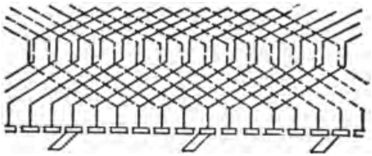

FIG. 115.—Wave winding.

shaft. The arrows indicate the air currents set up by the revolving of the armature.

The two most common windings are known as the wave shown in Fig. 115, and the lap-winding

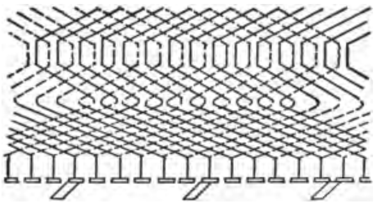

FIG. 116.—Lap winding.

shown in Fig. 116. The wave form of winding is employed in multipolar machines that use but two brushes. The connections can easily be traced when disconnecting the leads preparatory to rewinding.

Armature coils to be successfully made must be wound on forms and carefully shaped. When tearing apart a burned out armature, one of the old coils should be taken out carefully enough to preserve its original shape so that a sketch can be made and the dimensions taken. Fig. 117 shows the essential parts of the form used for the first process of making coils. The center *a*, and one side *b*, are shown in plain view and the opposite side *b′* in side elevation. The slots *c*, c^1, c^2 and c^3 are to receive pieces of cord for tying the completed coil together so that it will retain its shape until taped. The holes *d* and *d′* are to receive the bolts *f* and *f′*; *e* and *e′* are dowel pins, *h* one of the two thumb nuts that screw on the bolts *f* and *f′* to clamp the parts of the form together. The center *a* is permanently attached to the side *b* so that it can be removed with the coil intact, when it can be easily taken off the form. A boss *g* is bored and threaded to screw on the winding machine shown in Fig. 118. The slots in *b* and *b′* opposite the dowel pin *e* are for the coil ends. The winding machine is a simple device

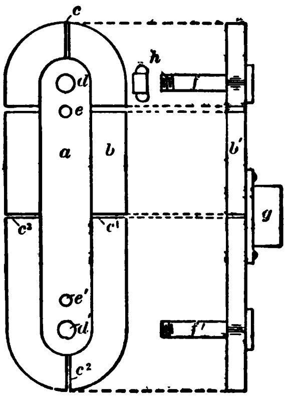

FIG. 117.—Essential part of the form used for the first process of making coils.

consisting of a spindle, on which the forms are screwed, the necessary gearing for speed reduction and a pulley for the driving belt. The driving motor can be mounted under the bench and the controller operated by a foot treadle.

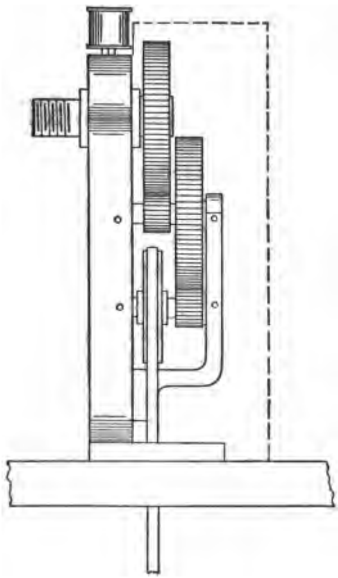

FIG. 118.—Winding machine.

A coil as formed in the first operation and partially taped is shown in Fig. 119. To shape the coil a device shown in Fig. 120 is used, consisting of a wood base to which grooved wood strips are attached. The sketch at the left shows an end

view of the form. One side of the coil is slipped into one groove and the other pulled over and slipped into the other groove as shown. The

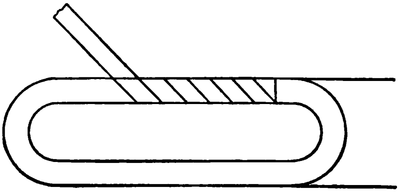

FIG. 119.—Taping a coil before it is formed.

ends are easily straightened with a mallet.

Fig. 121 shows several shapes of armature coils. The one shown at *a* is similar to that formed by the process just explained and is generally used. Coils shown at *b* and *c* require a mould corresponding to their shape and are, consequently, formed when winding.

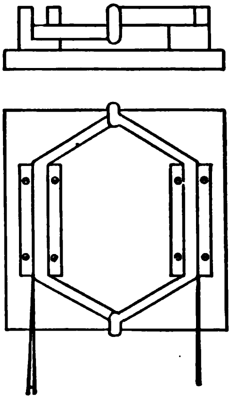

FIG. 120.—Coil forming device.

Great care must be exercised in insulating all cores before the winding is begun. For smooth core armatures, oiled paper, linen tape and shellac are principally used. Fuller board and mica or thin fiber are used for slotted armatures.

The manner of insulating a slotted armature is shown in Fig. 122. The insulation should pro-

ject beyond the surface of the core until the coils are in position and then trimmed. The manner of putting the coils in position is shown in Fig. 123. The figure represents the core of the armature laid out flat showing the slots *a*, *b*, *c*, etc., and three coils in position. In this case the first coil occupies

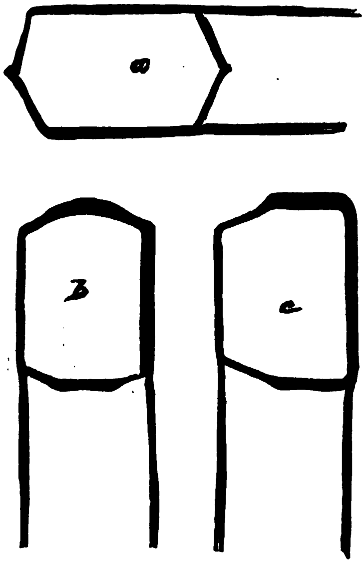

FIG. 121.—Armature coils.

the first and fifth slots, the second coil, the second and sixth slots, etc. In placing the coils in position in the core, one side only is driven in the slots until in the present case, five coils have been placed, when the remaining coils are put in their proper position.

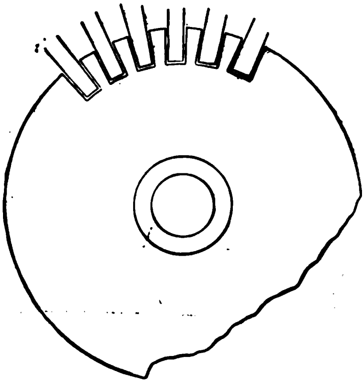

FIG. 122.—Method of insulating a slotted armature.

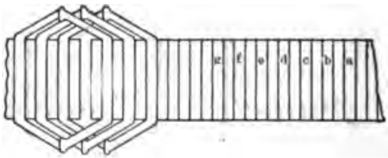

FIG. 123.—Method of putting coils in position.

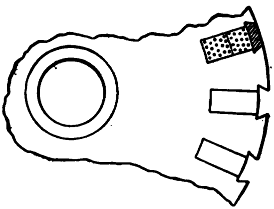

FIG. 124.—Slots with retaining wedges.

Fig. 124 illustrates the use of retaining wedges for holding the coils in position. These wedges are used in armatures, to a large extent, in place of bands over the core. They are made of hard wood that does not splinter easily and are driven in the small grooves provided for the purpose.

A completed armature is shown in Fig. 125. It is customary to place bands over the ends of the coils just beyond the edge of the core as shown,

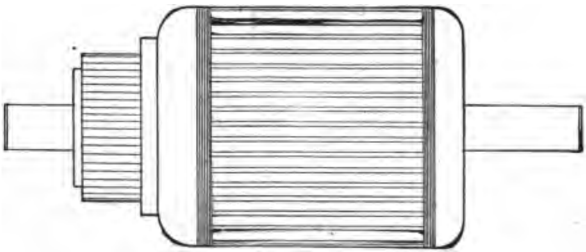

FIG. 125.—Complete armature.

which are wound on similar to the retaining bands used on commutators in course of construction.

No set rules for winding armatures can be given, as the workman must depend to a large extent upon the observation of the armatures taken apart. The suggestions given are intended to aid the work at the beginning.

Fig. 126 illustrates a soldering apparatus for soldering the leads in the commutator. The device is shown in section and the armature complete with a clamp on the shaft for lifting. A

circular metal bowl mounted on legs forms the solder pot. The melted solder should be kept up to the level of the dotted lines *a* and *a'*. A circular gas burner is shown below the pot. The armature is placed in position as shown, resting

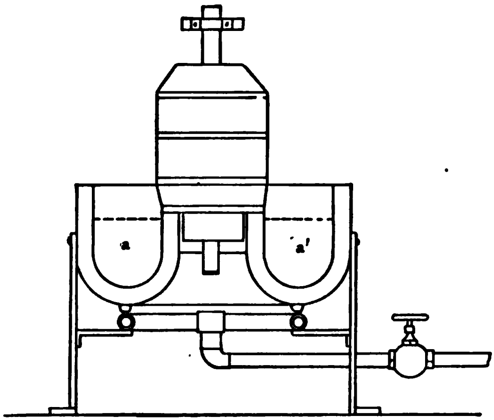

FIG. 126.—Soldering apparatus.

on the commutator shoulder, and the level of the solder raised by inserting a piece of heated metal such as iron or steel. Any size of commutator can be soldered by using bushings slipped over the commutator which will rest on the bowl.

CHAPTER VIII.

TABLES AND FORMULAS.

Ohm's Law.

$$I = \frac{E}{R} \qquad (1)$$

$$E = I R \qquad (2)$$

$$R = \frac{E}{I} \qquad (3)$$

Where I = the current strength in amperes,
R = the resistance in ohms,
E = the electromotive force in volts.

Formula No. 1 reads: The current in amperes equals the electromotive force in volts divided by the resistance in ohms.

Formula No. 2 reads: The electromotive force in volts equals the current in amperes multiplied by the resistance in ohms.

Formula No. 3 reads: The resistance in ohms equals the electromotive force in volts divided by the current in amperes.

ELECTRICAL POWER.

In every direct-current circuit the power in watts is equal to the product obtained by multiply-

ing the current in amperes by the electromotive force in volts.

In every direct-current circuit the power in watts lost in resistance is equal to the product obtained by multiplying the square of the current strength in amperes by the resistance of the circuit in ohms.

In every direct-current circuit the power in watts lost in resistance is equal to the quotient obtained by dividing the square of the electromotive force in volts by the resistance in ohms.

Let P = the watts of power,
E = volts of electromotive force,
I = current in amperes,
R = resistance in ohms.

Then $P = E\,I$ total watts,
$P = I^2\,R$ watts lost in resistance,

$$P = \frac{E^2}{R} \quad \text{“ “ “ “}$$

Let P_1 = horsepower,

Then $P_1 = \frac{P}{746}$.

EQUIVALENT OF ELECTRICAL UNITS.

(Hering.)

1 kilowatt = 1000 watts.
1 kilowatt = 1.34 hp.
1 kilowatt = 44,257 ft-lb. per minute.

1 kilowatt = 56.87 B.t.u. per minute.
1 horsepower = 746 watts.
1 horsepower = 33,000 ft-lb. per minute.
1 horsepower = 42.21 B.t.u. per minute.
1 B.t.u. (British thermal unit.) = 778 ft-lb.
1 B.t.u. = 0.2930 watt-hours.

OUTPUT AND EFFICIENCY OF MOTORS.

Let E = e.m.f. between mains,
E_m = counter e.m.f.,
I = current through armature,
i = current through shunt field.

For a series motor:
Total power supplied from mains = $I\,E$.
Power developed in armature = $I\,E_m$.

$$\text{Electrical efficiency} = \frac{I\,E_m}{I\,E} = \frac{E_m}{E}$$

For a shunt motor:
Total power supplied = $I\,E + i\,E$
Power developed = $I\,E_m$

$$\text{Electrical efficiency} = \frac{I\,E_m}{E\,(I+i)}$$

VOLTS OR AMPERES NECESSARY FOR GIVEN SIZE MOTORS.

$$E = \frac{746 \times P_1}{I \times n} \qquad I = \frac{746 \times P_1}{E \times n}$$

E = voltage of circuit.

I = amperes.
n = machine efficiency.
P_1 = horsepower.

MOTOR EFFICIENCY BY BRAKE HORSEPOWER.

$$\text{Efficiency} = \frac{746\ P_1}{E \times I} = \frac{P \times S}{7\ E \times I}$$

S = Speed in revolutions per minute,
D = torque in pounds at a distance of one foot from center of pulley,
E = voltage at terminals,
I = current in motor.

A more accurate method is to measure the input and the losses separately; then,

$$\text{Efficiency} = \frac{\text{Input–Losses}}{\text{Input}}$$

ALTERNATING-CURRENT FORMULAS.

Let f = frequency or number of cycles per second.
t = period or time of one cycle.

Then $f = \frac{1}{t}$.

An alternation equals one-half cycle therefore alternations = $f \times 2$.

POWER-FACTOR.

The power-factor in alternating-current circuits or apparatus may be defined as the ratio of the apparent electrical power to the real electric power in watts. As the current in alternating-current

apparatus is out of time phase with the electromotive force, the product of the instantaneous values of the current and electromotive force does not equal the real watts but gives the apparent watts.

If E = maximum value of e.m.f.,
I = maximum value of current,
θ = time angle between the current and e.m.f.

$$\text{Then true watts} = \frac{f \times d}{2} \times \cos\theta$$

COPPER FOR VARIOUS SYSTEMS OF DISTRIBUTION.

Power transmitted, distance, line loss and voltage same for all systems, all wires of each system same size.

System.	Copper required.
Two wire single-phase or direct-current	1.000
Three " " " " " "	.375
Four " " " " " "	.222
" " two " " " "	1.000
" " three " with neutral	.333
Three " " " delta	.75

ALTERNATING-CURRENT FORMULAS.

$$I = \frac{P}{E \times \cos\theta} \text{ for single-phase circuits.}$$

$$I = 0.50 \times \frac{P}{E \times \cos\theta} \text{ for two-phase circuits.}$$

$$I = 0.58 \times \frac{P}{E \times \cos\theta} \text{ for three-phase circuits,}$$

I = current in line in amperes,
P = power delivered in watts,
E = e.m.f. between mains in volts,
$\cos\theta$ = power-factor.

When the power-factor cannot be accurately determined it may be assumed as 0.80 for motor loads.

From the above formulas it will be seen that if P, E and $\cos\theta$ are the same, the

Current in each wire two-phase equals 0.5 current in each wire single-phase;

Current in each wire three-phase equals 0.58 in each wire single-phase;

Current in each wire three-phase equals 1.18 current in each wire two-phase.

TO FIND THE SIZE OF WIRE FOR ANY CURRENT ON A TWO-WIRE SYSTEM.

In general $r = \frac{e}{I \times 2d}$ or

$$A = \frac{10.8 \times 2d \times 8}{E}, \text{ in cir. mils.}$$

$$\frac{10.8 \times \text{twice the distance} \times \text{current in amperes}}{\text{drop in voltage}}$$

Example. What wire should be used to carry 450 amperes a distance of 600 feet, the allowable drop

being 6 per cent and the e.m.f. at the end of the circuit 115 volts.

$$\text{Volts at generator} = \frac{115}{0.94} = 122.3$$

$$\text{Volts lost in line} = 7.3$$

$$\text{Then } A = \frac{10.8 \times 2 \times 600 \times 450}{73} = 798{,}900 \text{ cir. mils.}$$

COPPER WIRE TABLE.

Number, American, or B. & S. Gage.	Copper Conductor. Diameter in mils.	Copper Conductor. Area in Circular mils.	Copper Conductor. Resistance, Ohms per 1000 ft. at 70° F.	Single Cotton-Covered Wire. Maximum Diameter in mils.	Single Cotton-Covered Wire. Turns per Linear Inch.	Single Cotton-Covered Wire. Turns per Square Inch.	Double Cotton-Covered Wire. Maximum Diameter in mils.	Double Cotton-Covered Wire. Turns per Linear Inch.	Double Cotton-Covered Wire. Turns per Square Inch.
0000	460.000	211,600.000	0.04904	472.000	1.80	3.60	478.00	1.70	3.21
000	409.600	167,800.000	0.06182	423.600	2.08	4.81	429.00	2.00	4.44
00	364.800	133,100.000	0.07798	376.800	2.38	6.29	384.00	2.32	5.98
0	324.900	105,500.000	0.09833	336.900	2.72	8.22	342.90	2.65	7.80
1	289.300	83,690.000	0.12400	301.300	3.07	10.37	307.30	2.99	9.93
2	257.600	66,370.000	0.15640	269.600	3.48	13.45	275.60	3.36	12.54
3	229.400	52,630.000	0.19720	241.400	4.00	17.33	247.40	3.80	16.04
4	204.300	41,740.000	0.24860	216.300	4.52	22.70	226.40	4.28	20.35
5	181.900	33,100.000	0.31330	193.900	5.05	27.22	207.90	4.83	25.92
6	162.000	26,250.000	0.39530	172.000	5.60	34.84	189.00	5.44	32.45
7	144.300	20,820.000	0.49840	154.300	6.23	43.12	173.30	6.08	41.07
8	128.500	16,510.000	0.62850	137.500	6.94	53.51	157.50	6.80	51.38
9	114.400	13,090.000	0.79200	122.400	7.68	65.53	142.50	7.64	64.96
10	101.900	10,380.000	0.99950	117.900	8.55	81.22	127.90	8.51	80.47
11	90.740	8,234.000	1.25900	96.740	9.60	102.40	112.70	9.58	101.97
12	80.810	6,530.000	1.59000	86.810	10.80	129.60	94.80	10.62	125.30

13	71.960	5,178.000	2.00400	77.960	12.06	161.60	80.96	11.88	156.80
14	64.080	4,107.000	2.52700	70.080	13.45	201.00	73.08	13.10	190.70
15	57.070	3,257.000	3.18600	63.070	14.90	246.60	66.07	14.68	239.40
16	50.820	2,583.000	4.01800	56.820	16.60	306.10	59.82	16.35	300.00
17	45.260	2,048.000	5.06700	51.260	18.20	368.10	54.26	18.08	363.20
18	40.300	1,624.000	6.38900	46.300	20.20	448.00	49.30	19.90	440.00
19	35.890	1,288.000	8.29000	41.890	22.60	567.10	44.89	21.83	528.50
20	31.960	1,022.000	10.16000	37.960	25.30	763.00	40.96	23.91	634.80
21	28.460	810.100	12.81000	34.460	28.60	908.80	37.40	26.20	762.70
22	25.350	642.400	16.17000	31.350	31.00	1,065.00	34.12	28.58	907.00
23	22.570	509.500	20.37000	28.570	34.30	1,307.00	30.60	31.12	1,075.00
24	20.100	414.000	25.69000	26.100	37.70	1,579.00	28.10	33.60	1,254.00
25	17.900	320.400	32.39000	23.900	41.50	1,914.00	25.90	36.20	1,456.00
26	15.940	254.100	40.85000	21.940	45.30	2,280.00	23.94	39.90	1,770.00
27	14.200	201.500	51.50000	20.200	49.40	2,711.00	22.20	42.60	2,016.00
28	12.640	159.800	64.94000	18.640	54.00	3,240.00	20.64	45.50	2,300.00
29	11.260	126.700	81.89000	17.260	58.80	3,841.00	19.36	48.00	2,560.00
30	10.030	100.500	103.20000	16.030	64.40	4,608.00	18.03	51.10	2,901.00
31	8.928	79.700	130.20000	14.930	69.00	5,290.00	16.93	56.80	3,585.00
32	7.950	63.210	164.20000	13.950	75.00	6,250.00	15.95	60.20	4,027.00
33	7.080	50.130	207.10000	13.080	81.00	7,290.00	15.08	64.30	4,594.00
34	6.305	39.750	261.10000	12.310	87.60	8,527.00	14.31	68.60	5,230.00
35	5.615	31.520	329.20000	11.620	94.20	9,860.00	13.61	73.00	5,921.00
36	5.000	25.000	415.20000	11.000	101.00	11,330.00	13.00	78.50	6,847.00
37	4.453	19.830	523.40000	10.450	108.00	12,960.00	12.45	84.00	7,392.00
38	3.965	15.720	660.00000	9.965	115.00	13,580.00	11.96	89.10	8,821.00
39	3.531	12.470	832.40000	9.531	122.50	16.670,00	11.53	95.00	9,805.00
40	3.145	9.888	1050.00000	9.145	130.00	18,780.00	11.15	102.50	11,650.00

AMERICAN OR B. & S. GAGE.

Gage No.	Diameter in mils or 1-1000 in.	Area in Circular mils.	Weight in Pounds per 1000 ft.	Feet per Pound.	Resistance of Pure Copper at 75° F.		
					Ohms per 1000 ft.	Feet per Ohm.	Ohms per Pound.
0000	460.000	211,600.00	639.33	1.56	.051	19,605.69	.0000708
000	409.640	167,805.00	507.01	1.97	.064	15,547.87	.0001270
00	364.800	133,079.40	402.09	2.49	.081	12,330.36	.0002020
0	324.865	105,534.50	319.04	3.13	.102	9,783.63	.0003200
1	289.300	83,694.20	252.88	3.95	.129	7,754.66	.0005100
2	257.630	66,373.00	200.54	4.99	.163	6,149.78	.0008110
3	229.420	52,634.00	159.03	6.29	.205	4,876.73	.0012890
4	204.310	41,742.00	126.12	7.93	.259	3,867.62	.0020500
5	181.940	33,102.00	100.01	10.00	.326	3,067.06	.0032600
6	162.020	26,250.50	79.32	12.61	.411	2,432.22	.0051800
7	144.280	20,816.00	62.90	15.90	.519	1,928.75	.0082400
8	128.490	16,509.00	49.88	20.05	.652	1,529.69	.0131100
9	114.430	13,094.00	39.56	25.28	.824	1,213.22	.0208300
10	101.890	10,381.00	31.37	31.88	1.040	961.91	.0331400
11	90.742	8,234.00	24.88	40.20	1.311	762.93	.0526900
12	80.808	6,529.90	19.73	50.69	1.653	605.03	.0837700

13	71.961	5,178.40	15.65	63.91	2.034	479.80	.1332100
14	64.084	4,106.80	12.41	80.59	2.628	380.51	.2118000
15	57.068	3,256.70	9.84	101.63	3.314	301.75	.3368000
16	50.820	2,582.90	7.81	128.14	4.179	239.32	.5355000
17	45.257	2,048.20	6.19	161.59	5.269	189.78	.8515000
18	40.303	1,624.30	4.91	203.76	6.645	150.50	1.3539000
19	35.390	1,288.10	3.78	264.26	8.617	116.05	2.2772000
20	31.961	1,021.50	3.09	324.00	10.566	94.65	3.4230000
21	28.462	810.10	2.45	408.56	13.323	75.06	5.4430000
22	25.347	642.70	1.94	515.15	16.799	59.53	8.6540000
23	22.571	509.45	1.54	649.66	21.185	47.20	13.7630000
24	20.100	404.01	1.22	819.21	26.713	37.43	21.8850000
25	17.900	320.40	.97	1,032.96	33.684	29.69	34.7950000
26	15.940	254.01	.77	1,302.61	42.477	23.54	55.3310000
27	14.195	201.50	.61	1,642.55	53.563	18.68	87.9790000
28	12.641	159.79	.48	2,071.22	67.542	14.81	139.8930000
29	11.257	126.72	.38	2,611.82	85.170	11.74	222.4490000
30	10.025	100.50	.30	3,293.97	107.391	9.31	353.7420000
31	8.928	79.71	.24	4,152.22	135.402	7.39	562.2210000
32	7.950	63.20	.19	5,236.66	170.765	5.86	894.2420000
33	7.080	50.13	.15	6,602.71	215.312	4.64	1,421.6460000
34	6.304	39.74	.12	8,328.30	271.583	3.68	2,261.8200000
35	5.614	31.52	.10	10,501.35	342.443	2.92	3,596.1040000
36	5.000	25.00	.08	13,328.83	431.712	2.32	5,715.3600000
37	4.453	19.83	.06	16,691.06	544.287	1.84	9,084.7100000
38	3.965	15.72	.05	20,854.65	686.511	1.46	14,320.2600000
39	3.531	12.47	.04	26,302.23	865.046	1.16	22,752.6000000
40	3.144	9.89	.03	33,175.94	1,091.865	.92	36,223.5900000

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